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(NASA-CR-170984) DEFINITION OF TECHNOLOGY DEVELOPMENT MISSIONS FOR EARLY SPACE STATIONS ORBIT TRANSFER VEHICLE SERVING. PHASE 2, TASK 1: SPACE STATION SUPPORT OF OPERATIONAL OTV (General Dynamics/Convair) N84-19377

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DEFINITION OF TECHNOLOGY DEVELOPMENT MISSIONS FOR EARLY SPACE STATIONS ORBIT TRANSFER VEHICLE SERVICING PHASE II

TASK 1 SPACE STATION SUPPORT OF OPERATIONAL OTV SERVICING

December 1983

GENERAL DYNAMICS
Convair Division

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TASK 1 SPACE STATION SUPPORT OF OPERATIONAL OTV SERVICING

December 1983

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FOREWORD

This study report was prepared by General Dynamics Convair Division (GDC) for the National Aeronautics and Space Administration Marshall Space Flight Center (NASA/MSFC) in accordance with Contract NAS8-35039, Data Requirement Number DR-4. The results were developed from June 1983 to November 1983.

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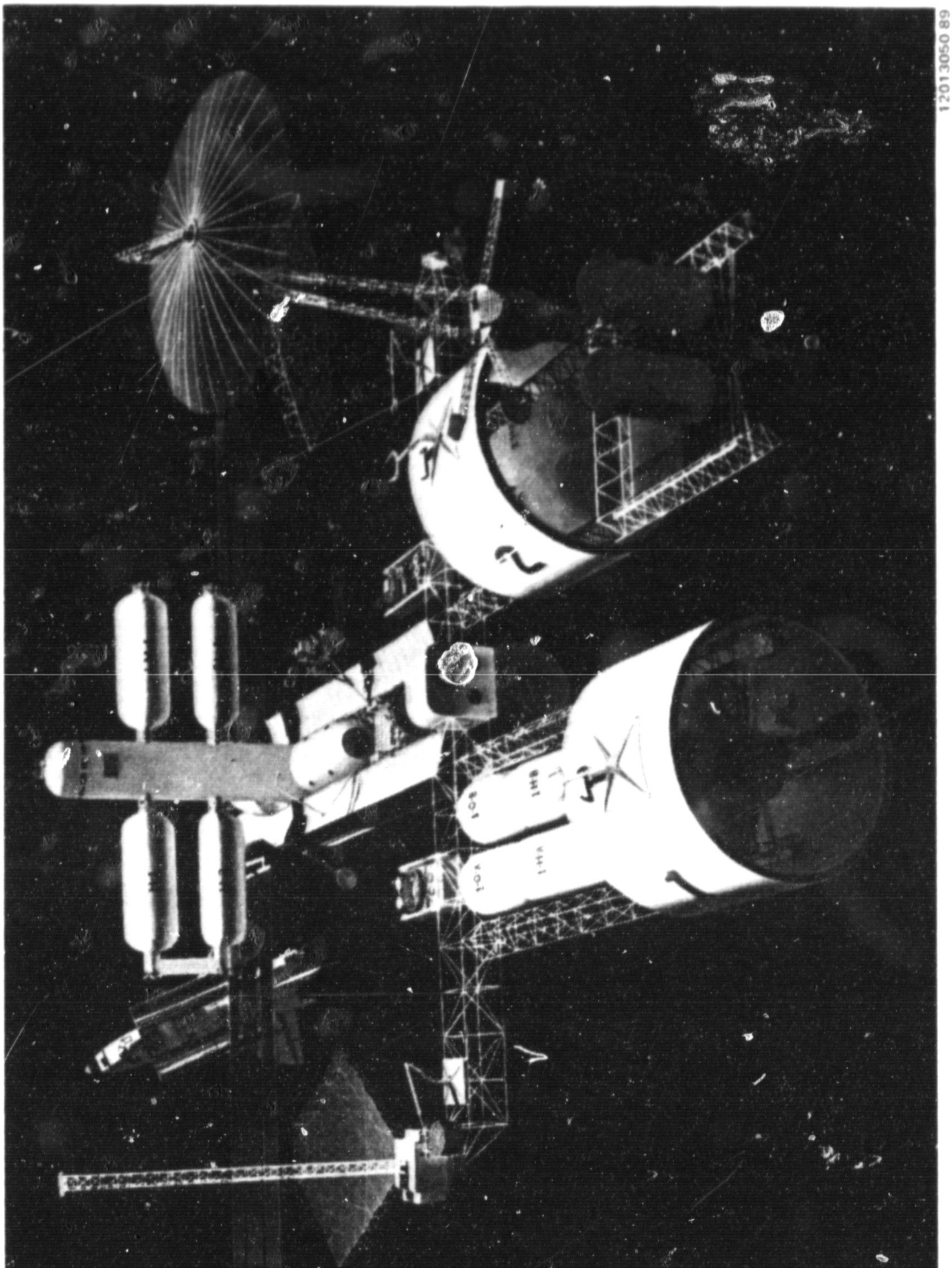
ACRONYMS

ACS	Attitude Control System
AEU	Aft Electrical Unit
APU	Auxiliary Power Unit
ATP	Authority to Proceed
C&W	Caution and Warning
CCW	Counter Clockwise
CDG	Concept Development Group
CDR	Critical Design Review
cg	Center of Gravity
DDT&E	Design, Development, Test and Evaluation
EMU	Extravehicular Maneuvering Unit
ET	External Tank
ETR	Eastern Test Range
EVA	Extravehicular Activity
FRSI	
GDC	General Dynamics Convair Division
GEO	Geostationary Earth Orbit
GH_2	Gaseous Hydrogen
HLLV	Heavy Lift Launch Vehicle
I_{sp}	Specific Impulse
IMS	Integration Management System
IOC	Initial Operational Capability
IUS	Inertial Upper Stage
IVA	Intravehicular Activity
JSC	Johnson Space Center
LEO	Low Earth Orbit
LeRC	Lewis Research Center, NASA
LH_2	Liquid Hydrogen
LO_2	Liquid Oxygen
LRU	Line Replaceable Unit
MBA	Multiple Berthing Adapter
MLI	Multi-Layer Insulation
MM	Manned Mission Module
MSFC	Marshall Space Flight Center, NASA
O/F	Oxygen-to-Fuel
OMS	Orbital Maneuvering System
OMV	Orbital Maneuvering Vehicle
ORUS	Orbital Replacement Units
OTV	Orbit Transfer Vehicle
P/L	Payload
PDR	Preliminary Design Review
PTA	Propellant Transfer Arms
Q/A	Quality Assurance

ACRONYMS, Contd

R/R	Remove/Replace
RCA	Remote Controlled Arm
RF	Radio Frequency
RFP	Request for Proposal
RMS	Remote Manipulator System
RU	Replacement Unit
S/C	Spacecraft
SBOTV	Space-Based OTV
SOFI	Spray-on Foam Insulation
SS	Space Station
STS	Space Transportation System
TBD	To be Determined
TDM	Technology Development Mission
TMS	Teleoperator Maneuvering System
TPS	Thermal Protection System
TV	Television
VRCS	Vernier Reaction Control System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SECTION 1

INTRODUCTION

The Space Station studies, which have just recently been performed by industry, have shown that there can be economic advantages to space-based Orbit Transfer Vehicles (OTVs) compared to ground-based OTVs. The Definition of Technology Development Missions for Early Space Station-Orbit Transfer Vehicle Servicing Study as well as the Space Station Studies have generated preliminary operational scenarios and requirements for space-based OTVs. In addition, the Phase I OTV Servicing Study has defined required tehnology advancements and preliminary Technology Development Missions (TDM) to be carried out on an early Space Station. These TDMs have been prioritized to indicate the order in which they should be carried out to efficiently develop and demonstrate the capability to support a space-based OTV by an operational Space Station. Now that the ground work has been established in the area of space-based OTV operations technology, additional definition is required to pursue an effective technology development plan. This study effort will address both the OTV and the Space Station by identifying in further detail and generating an integrated development plan for the required technology to demonstrate the space-based servicing capability.

This study effort is the second phase to be undertaken by the contractor for the definition of TDMs for the early Space Station. Specifically this study is for the definition of TDMs related to OTV servicing and will be concurrent with other studies to define TDMs related to satellite servicing and large space structures.

1.1 OBJECTIVE

The objectives of this study are to:

a. Define the testbed role of an early (1990) manned Space Station in the context of a space-based OTV evolutionary development and flight demonstration technology plan that results in an OTV servicing operational capability by the mid 1990s.

b. Refine the definition of selected priority OTV servicing technology development missions to be performed on an early Space Station.

c. Generate an integrated OTV servicing technology development plan that includes ground, Shuttle sortie, and Space Station activities.

d. Identify OTV servicing operations which can be performed by an initial Space Station.

e. Perform an operations analysis to identify the functions that a Space Station must perform to totally support an operational spacebased OTV fleet.

1.2 STUDY APPROACH

Figure 1-1 is a task flow and logic diagram of the overall study approach. It highlights principal tasks and their relationships to periodic reviews. The technical work will be accomplished in 16 months, with reporting completed 2 months later. In addition to formal reviews, we plan data exchange meetings by telephone or by travel, if necessary.

Task 1 performs an operations analysis to identify the functions that a Space Station must perform to provide total support of an operational space-based OTV. Alternative means to perform these functions will be identified and through tradeoffs the most viable approaches selected. The technologies to be developed to provide the selected servicing capabilities will be identified (see Section 1.3).

In Task 2 we will also determine the capability of the initial Space Station to support and service an operational ground-based OTV to allow an early operational mission (1990-1992 time frame). The capability of a single mission such as payload/OTV mating, checkout, and launch will be analyzed as well as the capability to service the OTV for any maintenance. We will determine the number of OTV missions that can be flown from the initial Space Station along with incremental additions to the station to perform additional numbers of missions. From this analysis, we will identify ground and space transportation system technology demonstration missions required to enable OTV servicing at an initial Space Station.

Using the data from the first two tasks, we will generate an integrated technology development plan for the technologies required to perform the OTV servicing mission. The plan will include definition of the tests and experiments to be accomplished on the ground, in Space Shuttle sortie missions, and on the early Space Station to maximize the benefits of the program. The plan will reflect and accomodate current and projected research and technology programs where appropriate. The data from the first three tasks will be presented at the interim review.

After the interim review, we will begin with refining the definition of the top-priority TDMs from the Phase I study. Based on the results of this effort, we will revise and refine the test matrixes for the development tests that should be performed on the ground, on a Space Shuttle sortie mission, at an early Space Station, or with a combination of these. The objectives and requirements of the Space Station development tests will then be updated.

Based on these updated requirements, we will deepen, refine, and update the designs of the top-priority TDMs that would be performed on an early Space Station. System-level trades will be reassessed and refined to ensure viability of the TDM designs. The end-to-end operations analysis for the TDMs will be refined and updated to more detail. We will establish which functions should be manned and which should be automated, generate timelines, determine manpower requirements and skills, and establish requirements for special support equipment on the Space Station.

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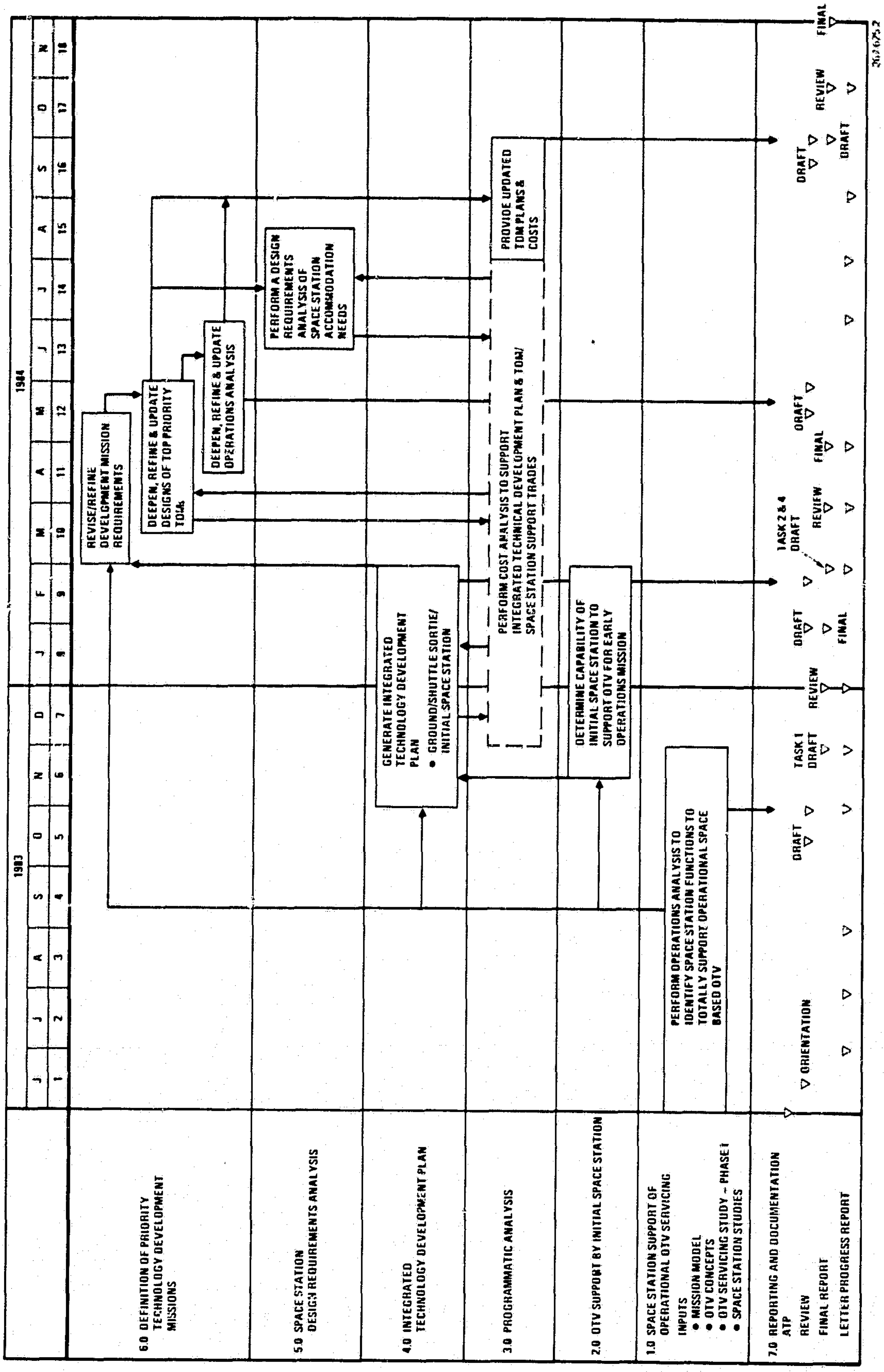

Figure 1-1. Program Task Flow

Using the data from the previous task and from the Phase I study, we will define the operational and physical interface requirements between the TDMs and the early Space Station. Based on these requirements, we will then refine the definition of the Space Station special support equipment, the functional operations required on the Space Station, the crew support, and the scars to the initial Space Station for growth to the operational missions.

Data from Tasks 6.1, 6.2, and 6.3 will be input to Task 3 to provide the basis for generating the necessary program plans, schedules, and cost analysis to support the TDM element trades, the special Space Station support equipment trades, and the Integrated Technology Development Plan. In addition, we will update the preliminary program planning for the selected technology development missions.

1.3 TASK 1 APPROACH

We began by performing an operations analysis of a ground-based OTV to use as a data base for our space-based analysis. We then performed an operations analysis to identify the functions that a Space Station must perform to provide total support of an operational space-based OTV. Operational functions such as rendezvous, docking and berthing, maintenance (both scheduled and unscheduled), OTV/payload integration, propellant transfer and storage, and checkout and launch were analyzed. Alternative means to perform these functions were identified and tradeoffs performed to select the most desirable approach. We defined how each operational function would be mechanized and implemented. Manpower involvement and timelines were generated along with support equipment requirements. We investigated the functional requirements for servicing a manned module. In addition, OTV fleet operations were analyzed along with the activation of servicing requirements prior to IOC. An evaluation was performed, using the tradeoff data, and the most viable OTV servicing approaches were selected. The output of the task was the identification of the technologies required to be developed to achieve the viable OTV servicing capabilities.

Under subcontract, Hamilton Standard assisted us in the mission definition and operations analysis tasks. They have extensive experience in areas dealing with EVA integration, operations, and applications and made direct contributions to requirements, concepts, trade studies, and operations analyses. As supplier of the Space Shuttle extravehicular mobility unit (EMU), Hamilton Standard is the major source of study data on the use and application of this device and ancillary equipment. Their background includes the most current space operations and satellite servicing studies.

The following sections present the results of Task 1.

SECTION 2

OPERATIONAL OTV SERVICING

This section identifies 1) a representative space-based Orbit Transfer Vehicle (OTV) that was used in the operations analysis at the Space Station, 2) the tasks and timelines to turn around a ground-based OTV to establish a data base for analyzing turnaround operations on a Space Station, 3) functional requirements for servicing a space-based OTV at the Space Station, 4) candidate servicing facilities to meet the operational requirements, 5) candidate concepts for delivering propellants to the Space Station, 6) functional requirements for servicing a manned module, 7) Space Station accommodation concepts for OTV servicing, 8) end-to-end mission operational tasks, 9) comparison of ground-based versus space-based servicing tasks, 10) the activation of servicing facilities prior to IOC, and 11) OTV fleet operations requirements.

2.1 REPRESENTATIVE SPACE-BASED OTV

The recent Space Station studies performed by industry have indicated the economic advantages a space-based OTV can generate as compared to a ground-based OTV. This advantage is dependent on an OTV that is optimized for the space environment and on-orbit maintenance. The definition of an optimized space-based OTV has not yet been accomplished. However, to understand the Space Station servicing functions for a space-based OTV, we needed a representative space-based OTV. In our Phase I study (GDC-SO-83-052) we developed a representative space-based OTV along with preliminary weights and performance data. Our concept for this study is essentially the same with some update. A summary of the concept follows. More detail can be found in the Phase I report.

Table 2-1 lists the driving design requirements for the space-based OTV to meet the mission model. It shows the maximum delivery payload weights envisioned for a single flight. Payload lengths are not shown since they are not a design driver as they can be for a ground-based OTV. The unmanned and manned servicing mission requirements are also design drivers, especially the return payload requirements. The descriptions of these payloads and their missions can be found in the Space Transportation System Nominal Mission Model (FY 1983-2000) Revision 6, October 1982, prepared by Donald Saxton, Program Development, MSFC. A wide range of OTV concepts addresses the key issues shown in Figure 2-1. Our baseline vehicle, illustrated on the upper right, served as the basis for generating the servicing requirements.

Table 2-1. Mission Model Payload Requirements

Item	Weight (klb)	Mission
Operational GEO platform	14.0	Deliver
Large platform	Multiple OTV flights	Deliver
Other satellites	Multiple satellites to 14.0	Deliver
GEO station element	16.0	Deliver
Unmanned servicing	6.0 up 2.0 down	Roundtrip to GEO
Manned sorties	14.0 up 14.0 down	Roundtrip to GEO
Solar system exploration	Up to 12.0	Escape

The baseline Orbit Transfer Vehicle Concept (Figure 2-2) is for an advanced OTV designed specifically for the space environment, and with modular philosophy to simplify logistics, maintenance, and reconfiguration for different missions. Vehicle elements peculiarly adaptable to a space-based vehicle are:

a. Lightweight spherical propellant tanks

b. Modular tankage arrangement for mission flexibility

c. Fixed aerobrake

d. Lightweight open truss structure

e. Universal payload interface module

f. Quick changeout astrionics, attitude control system (ACS), propellant feed, and main engine modules

g. Fixed high-area-ratio engine nozzles

The core section for this concept is a truss beam that contains subsystems such as plumbing, disconnects, astrionics, and a payload interface. This core section is regarded as the primary portion of the vehicle with provisions to allow quick changeout of components such as the tanks, engine(s), and astrionics packages.

ADVANTAGES
- FREE FROM SHUTTLE CONSTRAINTS (SIZE, LOADS)
- REUSABLE (LOWER COST)
- MODULARITY (MIX & MATCH CAPABILITY)

KEY ISSUES
- LONG-TERM SPACE EXPOSURE
- ORBITAL INTEGRATION, SERVICING
- EFFICIENCY (LOW WEIGHT, HIGH ISP)
- LOW-COST OPERATIONS (PROPELLANT DELIVERY TO LEO)
- DEPLOYMENT & RETRIEVAL
- FUTURE PAYLOADS & MISSION CHARACTERISTICS

TECHNOLOGY NEEDS
- LIGHTWEIGHT (THIN GAGE) TANKS
- LIGHTWEIGHT (COMPOSITE) STRUCTURE
- LIGHTWEIGHT/HIGH TEMPERATURE AEROBRAKE MATERIALS
- LONG LIFE/SPACE MAINTAINABILITY ENGINE (LOW WEIGHT, HIGH ISP)
- CRYOGENIC PROPELLANT MANAGEMENT – THERMAL CONTROL (MLI INSULATION, MIXING, VENTING), PROPELLANT ACQUISITION GAGING
- METEOROID & SPACE DEBRIS PROTECTION
- REDUNDANT, FAULT-TOLERANT, HARDENED AVIONICS
- AUTO RENDEZVOUS/DOCKING

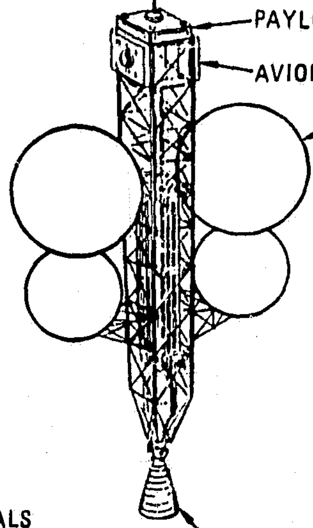

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Figure 2-1. Space-Based OTV

Referring to Figure 2-2, this concept uses eight tanks attached to the core section with cantilever trusses. The trusses are fixed to the tanks and interface with the core section through a systems disconnect panel and structural attachments. These cantilever trusses provide a means for supporting and handling the tanks during transportation, during connection and disconnection from the core section, and as a holding device during storage. A typical tank attachment consists of engaging the hinge side of the cantilever truss to the core truss and rotating until the structural latches engage. A retractable disconnect panel on the core section is then actuated, which engages the disconnect fittings.

The fuel tanks are supported from the oxidier tanks with a truss system. One complete tank module is composed of an oxidizer tank, a fuel tank, an interconnecting truss, and the cantilever truss, which is plugged into the core section. The truss members between the tanks are equipped with drag struts at the forward ends for lateral support and disconnection from the core section, and as a holding device during storage. A retractable disconnect panel on the core section actuates to engage the disconnect fittings.

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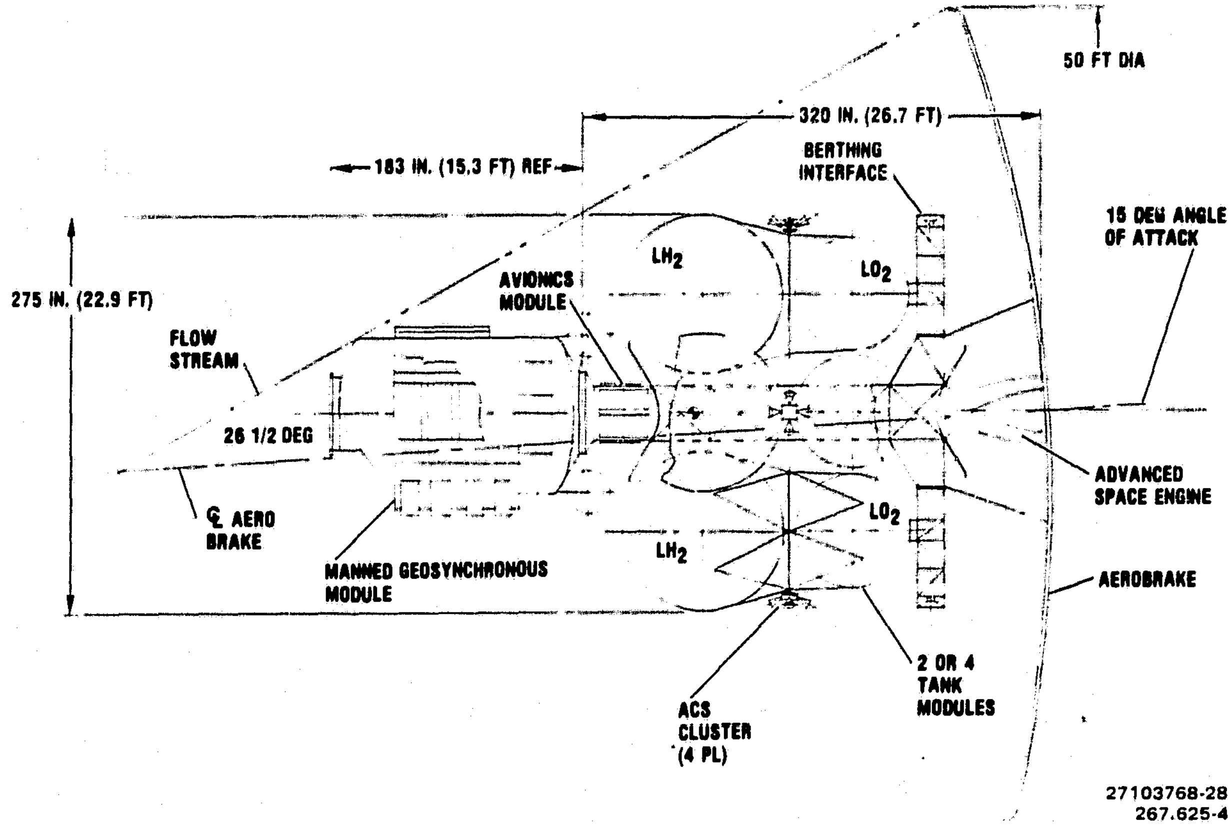

Figure 2-2. Representative Space-Based OTV Concept

The aerobrake is supported from the core section with a conical struss structure and is equipped with two doors for covering the engine opening. An alternate procedure would delete these doors and run the engine at low-idle mode during atmospheric braking.

The forward end of the core section is equipped with an octagon structure called the astrionics module that houses the astrionic packages and provides an interface for the payload. The astrionics packages can be quickly disconnected from this module for transport to a shirtsleeve Space Station module for maintenance or for return to Earth.

The aft end of the core module has an interface panel for the engine package. This interface panel contains disconnects for all the engine fluid and electrical lines and also contains a structural latch system for securing the engine package to the core section. A typical engine package consists of a flat interface panel with disconnects, a thrust cone, a set of gimbal lines, and a thrust vector control system. This package contains all engine systems and is designed to plug onto the core section as a single package.

Four ACS modules are located on a support beam between the tanks and outboard of them. Each of these ACS modules is a complete, self-contained unit consisting of a spherical tank, an acquisition system, a cluster of thrusters, electrical wiring harnesses (with a disconnect), and an interface boss for "quick" type connection to the core section. The propellant is hydrazine. Prior to installation the tanks are charged with propellant, pressurized, and locked up.

An alternate ACS that maximizes performance and reduces the number of propellants that must be provided at the station is a two-gas (or two-liquid) LO_2/H_2 ACS drawing propellant from a start basket in the main tanks.

A third possibility under consideration is an ACS that uses hydrogen gas. Slugs of liquid hydrogen are taken from the main tanks and injected into a hot flash tank that in turn feeds the thrusters. This alternate ACS will require a slug pump, interconnecting plumbing, and a pressure control system. The thrusters would be modularized for simple one-step plug-in type replacement.

The four-tank module version of the OTV is used for the manned mission. The two-tank module OTV can be used for the payload delivery only missions.

2.2 GROUND-BASED VEHICLE TURNAROUND ASSESSMENT

Figure 2-3 is a road map showing how we have extrapolated our present experience with cryogenic upper stages to arrive at the tasks/manhours/number of men for a space-based operation. We are using actual Centaur experience for receive and launch operations. The GDC personnel at the Eastern Test Range (ETR) were very helpful in obtaining this data for the study. That experience has been used in the past to come up with projected turnaround tasks for a ground-based vehicle. This was accomplished on the Space Tug Study in the early 70s (Reference 1). We also looked at the turnaround of a ground-based OTV in a study for MSFC in 1980 (Reference 2). Using this information as a data base, we performed an operations analysis in both Phase I and Phase II of the study to identify the required space-based operations/timelines/manpower. In this task we had the help of our subcontractor, Hamilton Standard. They have extensive experience in space operations, especially EVA.

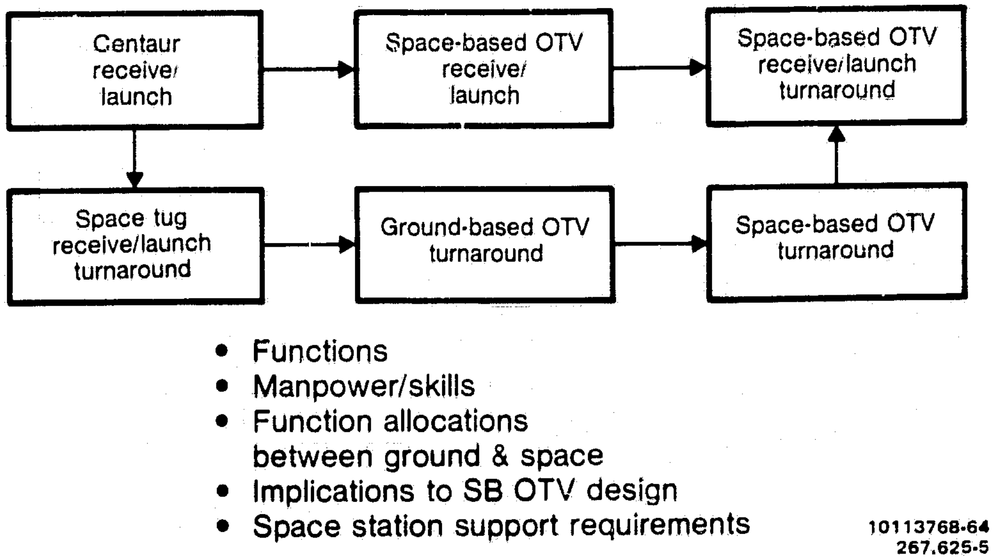

Figure 2-3. Extrapolation of Current Ground-Based Operations to Space-Based Operations

The following displayed information indicates the ground operations for a ground-based OTV and later on in the report (Section 2.5) these will be compared with the proposed space-based operations.

2.2.1 GROUND-BASED VEHICLE MAINTENANCE CHARACTERISTICS. We have made an assessment of how we would turn around a ground-based vehicle under today's conditions at our facility at ETR in Florida. This was done to identify the tasks to be performed, the timelines, and the number of different personnel involved. We used this as a data base for generating the turnaround tasks to be accomplished at the Space Station for a space-based OTV.

First of all we must characterize a present day reusable, ground-based vehicle and how it is processed on the ground so that a comparison with an improved state-of-the-art space-based vehicle can be meaningful. Table 2-2 lists the characteristics of a potential present day reusable, ground-based vehicle and indicates how it would be handled at ETR. The background of how we have checked out and launched upper stages in the past has a big impact on the approach used today. Present day vehicles were not designed using maintainability and accessibility as design drivers. The types of operations required to be performed are fairly labor intensive. In addition, a ground-based vehicle must be downloaded, uploaded, and integrated with the Shuttle.

Table 2-2. Ground-Based Vehicle Turnaround Assessment

- Ship, integrate & launch status has not been attained
  - Tendency to ship short & assemble missing parts later
  - Requires some disassembly & component checkout
  - Assumes man can compensate for system shortcomings
- Vehicles designed primarily for performance optimization
  - Maintainability & accessability not a design driver beyond providing access panels
- Checkout accomplished with GSE external to vehicle
  - Requires multiple interfaces (manual connection)
- Personnel required to analyze data & write maintenance plan
- Preventive & corrective maintenance accomplished manually
- Inspection requires dismantling to verify vehicle integrity
- Operation requires download, upload & integration with shuttle
- Operation requires transport & interface with maintenance facility
- QA & safety support required because of dismantling process & personnel involvement

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2.2.2 GROUND-BASED VEHICLE TURNAROUND TASKS. Figure 2-4 is a top-level, functional flow diagram for ground-based operations, which outlines the major processes and resources involved within the system. Table 2-3 identifies the next level ground-based operational functions. Table 2-4 identifies the major tasks, elapsed times, and manhours required to turn around a potential present day, reusuable ground-based cryogenic vehicle characterized in Table 2-2. This data was synthesized from our present day operations with Centaur, Shuttle Centaur, and a ground-based operations study conducted several years ago on a potential ground-based vehicle (Reference 1). The total task time and total manhours are indicated. Later in the report, these tasks will be compared to the tasks required at the Space Station (Section 2.5) to provide traceability to our present data base on turning around a cryogenic upper stage.

2.2.3 GROUND-BASED VEHICLE TURNAROUND PERSONNEL REQUIREMENTS. Table 2-5 indicates the number and types of personnel required to support the ground-based operations for the present Shuttle/Centaur. The hands-on personnel are the technicians/mechanics and the Q/A personnel. Engineers are required to support the operation and their number is shown. Other types of personnel are also required to keep the operations we have at ETR going such as transportation personnel, security, etc. These are also shown. In addition to these personnel, there are indirect personnel such as supervisors, accounting, etc. These are not included in the 170 number.

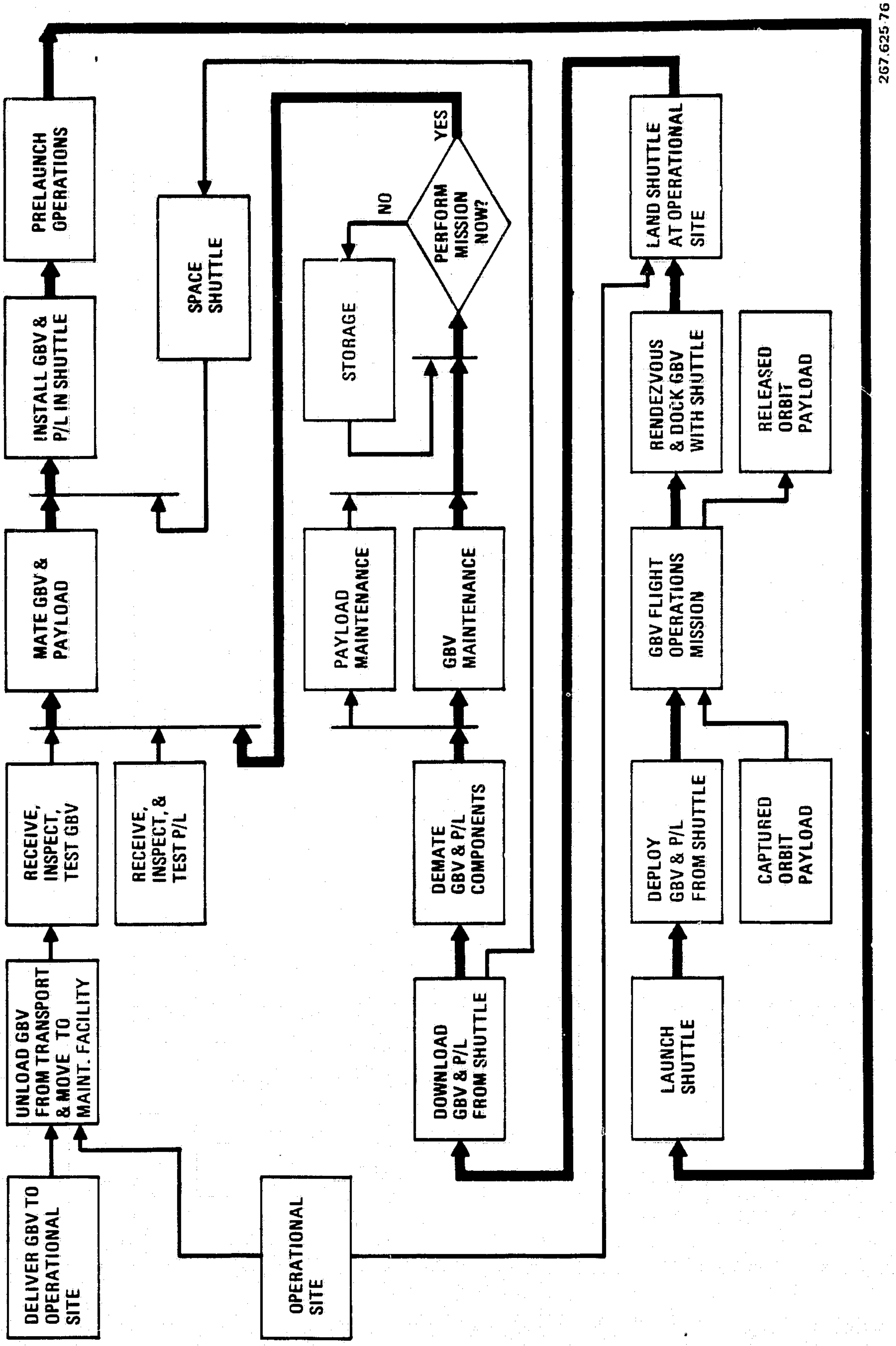

Figure 2-4. Ground-Based Vehicle (GBV) Operations

Table 2-3. Ground-Based Vehicle (GBV) Operational Functions

LAND SHUTTLE
- LAND SHUTTLE AT OPERATIONAL SITE

PURGE PROPELLANTS
- CONNECT EQUIPMENT TO SHUTTLE
- SAFE SHUTTLE & GBV
- PURGE GBV MAIN PROPELLANT TANKS

DOWNLOAD GBV FROM SHUTTLE
- REMOVE GBV FROM SHUTTLE
- REMOVE FLIGHT DATA RECORDER TAPES FROM GBV
- TRANSFER GBV TO MAINTENANCE FACILITY
- TRANSFER GBV TO MAINTENANCE – TEST STAND

INSPECT GBV
- PERFORM VISUAL INSPECTION
  - REMOVE GBV ACCESS DOORS & CONNECT GSE
  - INSPECT GBV
- ANALYZE DATA & PREPARE MAINTENANCE PLAN
- PERFORM SCHEDULED CHECKOUT & FAULT ISOLATE
- REVIEW INSPECTION & CHECKOUT RESULTS & COMPLETE MAINTENANCE PLAN

PERFORM GBV MAINTENANCE
- PERFORM SCHEDULED & UNSCHEDULED MAINTENANCE
- PERFORM SYSTEMS TEST
- PREPARE GBV FOR STORAGE IF REQUIRED

MATE GBV & PAYLOAD
- ATTACH LIFT BAR TO PALLET
- TRANSFER GBV & PALLET TO TRANSPORT TRAILER
- REMOVE LIFT BAR
- POSITION MATING WORK STAND
- HOIST PAYLOAD TO MATING POSITION
- MECHANICALLY JOIN GBV AND PAYLOAD
- CONNECT GBV & PAYLOAD INTERFACES
- VERIFY GBV & PAYLOAD INTERFACES
- PERFORM INTEGRATED SYSTEM TEST

INSTALL GBV & PAYLOAD IN SHUTTLE
- TRANSPORT GBV & P/L TO SHUTTLE
- INSTALL GBV & P/L IN SHUTTLE
- VERIFY GBV-P/L TO SHUTTLE INTERFACE
- CONDUCT SHUTTLE/GBV-P/L INTEGRATED TEST

LAUNCH SHUTTLE/GBV-P/L
- CONDUCT LAUNCH READINESS TEST
- LOAD PROPELLANTS & PRESSURANTS
- CONDUCT TERMINAL COUNTDOWN
- SHUTTLE LIFTOFF
- ENTER SPACE ORBIT

DEPLOY GBV-P/L FROM SHUTTLE
- PERFORM GBV-P/L PREDEPLOYMENT OPERATIONS
- CONDUCT GBV-P/L/SHUTTLE SEPARATION SEQUENCE
- GBV FREE FLIGHT OPERATIONS

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Table 2-4. Ground-Based Vehicle Turnaround Tasks

Time (hr)	MH	Task No.	Task
8:00	64:00	1.1.1	Analyze data & prepare maintenance plan
5:00	36:50	1.1.3	Transfer stage from pallet to maintenance & test stand
3:00	68:00	1.1.4	Remove stage access doors & connect GSE
11:00	288:00	1.1.5.1	Inspect structural elements & thermal control
		1.1.5.2	Inspect tanks, supports & interior
		1.1.5.3	Inspect MLI & thrust structure
		1.1.5.4	Inspect docking mechanism
		1.1.5.5	Inspect avionics & flight control units
		1.1.5.6	Inspect engine fluid & pressure lines
		1.1.5.7	Inspect fuel cells
4:00	32:00	1.1.6.1	Perform scheduled checkout & fault isolate
16:00	79:00	1.1.6.2	Perform leak check on LH_2 & LO_2 tanks & engine
		1.1.6.3	Inspect stage/orbiter interface
8:00	80:00	1.1.7	Review inspection & checkout results & complete maintenance plan
8:00	160:00	1.1.8	Perform unscheduled maintenance
20:00	842:00	1.1.9	Perform scheduled maintenance — structures
		1.1.10	Perform scheduled maintenance — avionics
		1.1.11	Perform scheduled maintenance — propulsion
		1.1.12	Perform scheduled maintenance — thermal control
1:00	8:30	1.2.1	Mate stage & stage/orbiter adapter
5:00		1.2.2	Check out docking mechanism
Not in timeline		2.1.5	Prepare for storage
		2.1.6	Monitor stage in storage
		2.1.7	Remove from storage
		2.1.8	Accomplish mission-peculiar preparations
16:00	320:00	2.1.9	Perform systems test
Not in time line		2.1.10	Correct faults
		2.1.11	Reverify system after correction
7:30	77:30	2.1.12	Secure from system test
3:30	52:30	2.2.5	Mate stage & spacecraft
1:00	8:00	2.2.6	Verify stage/spacecraft interface
Not in time line		2.2.7	Perform integrated system test
3:30	21:00	2.3.1	Transport payload (stage & spacecraft) to orbiter
6:30	77:00	2.3.2	Install in orbiter
2:00	24:00	2.3.3	Verify orbiter/payload interface
5:00	25:00	2.3.4	Conduct integrated systems test
1:00	4:00	2.3.5	Check status — stage/shuttle interface (after shuttle up-load)
3:00	12:00	2.4.1	Conduct orbiter/payload integrated test
1:00	4:00	2.4.2	Conduct launch readiness test (stage)
4:00	20:00	2.4.4	Load propellants & pressurants
0:25	1:30	2.4.5	Conduct terminal countdown
0:30	2:30	3.1.1	Safe stage
6:00	48:00	3.1.2	Purge main propellant tanks
0:30	1:00	3.1.3	Remove flight data recorder tapes
8:30	110:30	3.2.1	Remove stage from orbiter
2:00	18:00	3.3.1	Transfer stage to TMF

Total task-time = 152:45 hours
Total man hours = 2534:30 hours

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Table 2-5. Personnel Required to Perform Ground-Based Vehicle Turnaround Tasks

Total direct personnel Shuttle/Centaur (expendable)	One shift	Ground-Based Reusable Vehicle (1975 SOA) 24 Launches/Year 1st shift	2nd shift
Engineers	46 (27%)	36	12
Tech/mech	49 (29%)	26	18
QA	16 (9%)	9	6
		71	36
	(111)	107	
Other base support	59 (35%)		
	170		

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The data on the right indicate proposed numbers taken from our Space Tug study (Reference 2). Shown are the number of people projected in the three areas of interest. It was postulated that two shifts would be required to accomplish 24 launches a year. To meet a traffic model of approximately 15 launches a year, we believe only one shift would be required. Logically there should be an equivalent number of other base support personnel needed for the Ground-Based Reusable Vehicle operation as the Shuttle/Centaur.

Later in the report we will make a comparison of these later figures with the space-based operations and discuss the reason for the differences (Section 2.5).

2.3 FUNCTIONAL/OPERATIONAL REQUIREMENTS AND FACILITIES

The mission functional/operational analysis to identify the required servicing functions to be performed on the Space Station along with the candidate alternative facilities to meet these requirements is presented in this section. In addition, propellant transportation concepts to LEO, crew module servicing requirements, and Space Station accommodation concepts are discussed. This data was generated to drive out the technology requirements that must be developed to ensure the capability to service an OTV. In a later section of this report, an evaluation of the alternative approaches identified here is carried out to select the most viable technologies to be developed.

2.3.1 SPACE-BASED OTV FUNCTIONAL ANALYSIS. This section presents the results of the functional analysis performed during the study to drive out the design and operational requirements for servicing an OTV at a Space Station.

Figure 2-5 is a functional flow diagram for space-based OTV operations, which outlines the major processes and resources involved within the system. To maintain simplicity for presentation, communication links, navigational aids, and ground support functions are not shown in the first level diagram. These functions have been considered within the context of other gross functional listings.

The payload module may be either a payload delivered to orbit, an unmanned servicing module, or a manned module. Orbit payloads will be delivered to the desired orbit or perform servicing on-orbit, and then returned to the Space Station. It is acknowledged that receive, assemble, and demate processes are maintenance functions and are shown on this diagram to provide clarity of operations. The blocks that are cross hatched are the functions where we have developed detailed timelines, which are discussed in Section 2.4.

Lower level functional flow diagrams were developed in the areas where the OTV interfaces with the station for servicing. Table 2-6 lists the operational functions to be performed for the initial OTV delivery and assembly at this station. Section 2.4.3 describes the tasks and timelines for the initial delivery and assembly of the OTV.

Table 2-6. Initial OTV Delivery and Assembly Operational Functions

DOCK SHUTTLE TO STATION

- OPEN SHUTTLE DOORS
- RENDEZVOUS & DOCK SHUTTLE WITH STATION

OFFLOAD & ASSEMBLE OTV

- OFFLOAD & POSITION CORE SECTION FOR ASSEMBLY
- ASSEMBLE 1ST TANK TRUSS TO CORE SECTION
- ASSEMBLE 2ND TANK TRUSS TO CORE SECTION
- TRANSFER OTV CORE SECTION TO MAINTENANCE DOCK
- TRANSFER AND ASSEMBLE 1ST TANK MODULE TO TANK TRUSS
- TRANSFER AND ASSEMBLE 2ND TANK MODULE TO TANK TRUSS
- OFFLOAD AND DEPLOY AEROBRAKE
- TRANSFER AND ASSEMBLE ENGINE TO OTV
- ATTACH AEROBRAKE TO OTV
- INSPECT OTV ASSEMBLY

CHECKOUT OTV SYSTEM

- BRING ALL SYSTEMS ON LINE
- PERFORM OTV SYSTEM OPERATIONAL TESTING
- WHEN FAULT OR DAMAGE DETECTED
  - PERFORM DAMAGE ASSESSMENT
  - INITIATE FAULT ISOLATION ROUTINE
  - PERFORM OTV UNSCHEDULED MAINTENANCE
  - PERFORM OTV SYSTEM OPERATIONAL TESTING
- PROCEED WITH PAYLOAD INTEGRATION OR DEACTIVATE AND STOW OTV

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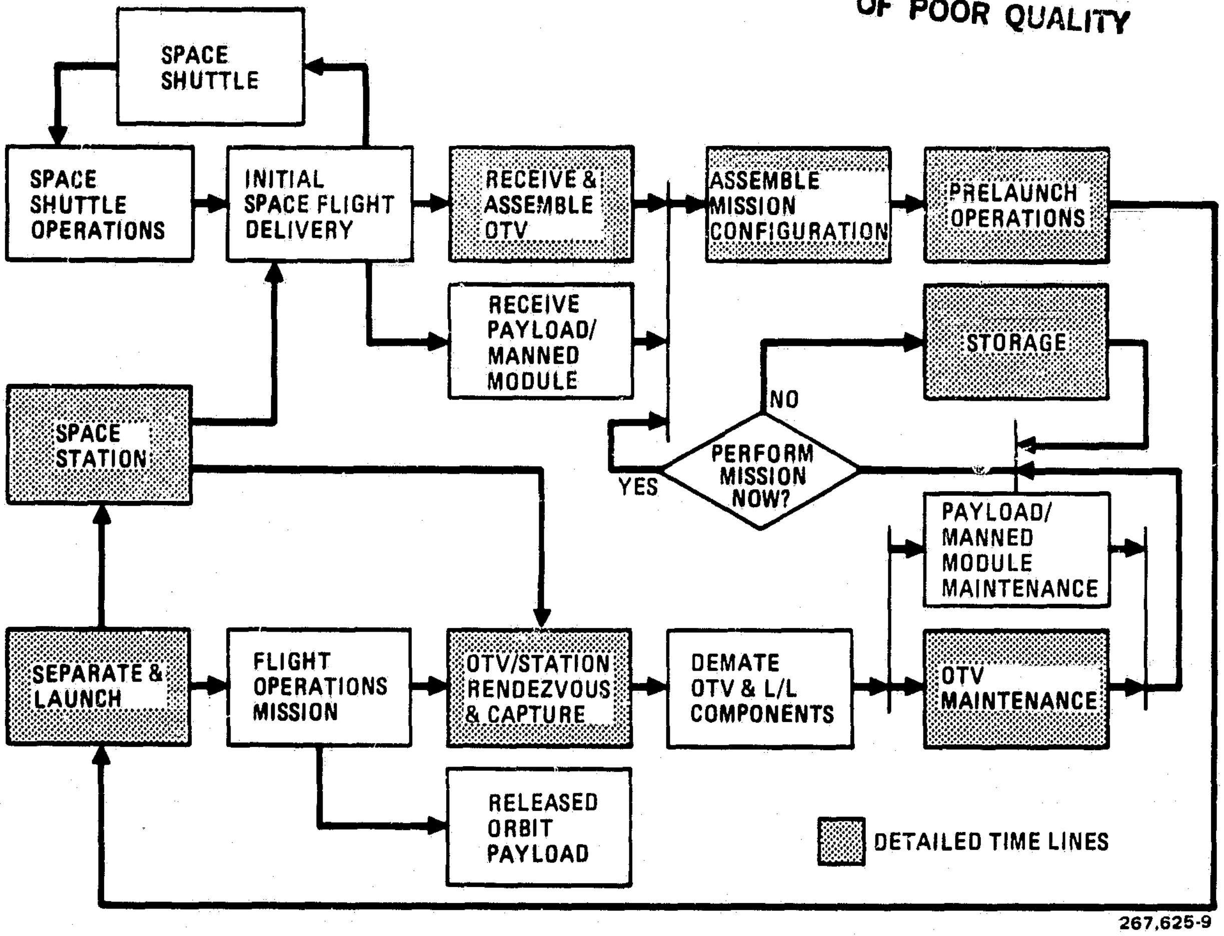

Figure 2-5. Space-Based OTV Operations

Table 2-7 lists the operational functions to be performed for OTV servicing. These requirements were used to drive the alternative servicing facilities designs presented in Section 2.3.

Table 2-8 lists lower level operational functions to be performed for OTV maintenance. These functional requirements drove the tasks discussed in Sections 2.4.1 and 2.4.2.

We used the data base developed from our ground-based OTV background (see Section 2.2) to help us develop the functions to be performed in space. Using this data base, instead of starting from a blank piece of paper, ensured that the lessons learned from the past would be incorporated in the space-based operations and that nothing would fall through the crack.

Table 2-7. OTV Servicing Operational Functions

BERTH OTV
- RENDEZVOUS OTV WITH STATION
- CAPTURE OTV AT STATION
- BERTH OTV AT STATION

TRANSFER PROPELLANT
- VERIFY INTERFACE INTEGRITY
- PERFORM PROPELLANT LEAK CHECK
- TRANSFER RESIDUAL PROPELLANT FROM OTV STATION

INSPECT OTV
- PERFORM VISUAL INSPECTION
- DETERMINE OTV FAULT STATUS
- WHEN FAULT OR DAMAGE DETECTED
  - PERFORM DAMAGE ASSESSMENT (TV/EVA)
  - INITIATE ELECTRICAL TEST ROUTINE TO VERIFY FAULT
  - INITIATE FAULT ISOLATION ROUTINE
- FORMULATE INTEGRATED MAINTENANCE PLAN

PERFORM OTV MAINTENANCE
- PERFORM SCHEDULED/UNSCHEDULED MAINTENANCE TASKS
- MISSION RECONFIGURE
- PERFORM SYSTEM OPERATIONAL TESTING
- DEACTIVATE & STOW OTV (IF NOT REQUIRED FOR MISSION AT THIS TIME)

MATE OTV & PAYLOAD
- TRANSFER PAYLOAD TO OTV
- MATE PAYLOAD TO OTV
- VERIFY OTV/PAYLOAD INTERFACE
- PERFORM OTV/PAYLOAD INTEGRATION TEST

LAUNCH OTV/PAYLOAD
- PERFORM PRELAUNCH OPERATIONS
- TRANSFER PROPELLANT FROM STATION TO OTV
- LAUNCH OTV/PAYLOAD

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2.3.2 CANDIDATE OTV SERVICING FACILITIES. From the Phase I study and other sources, we identified several candidate alternative approaches to servicing an OTV as called out on Figure 2-6. Also shown on the figure are some of the advantages and disadvantages of the candidate approaches. An additional option has been identified because of safety reasons; it is having a separate propellant depot away from the manned station. To identify viable technology requirements for OTV servicing, we felt we needed to analyze these options further.

The following sections present the operational functions, facility requirements, and the candidate facilities for the five options.

Table 2-8. Space-Based OTV Maintenance Functions

Perform scheduled maintenance
• Transfer propellant to & from OTV
• Perform visual inspection
• Determine OTV fault status
• Replace ACS modules (after each mission)
• Replace engine module (after TBD mission time)
• Perform system operational testing
• Service fuel cell (after TBD mission time)
Perform unscheduled maintenance
• Perform damage assessment (beyond scheduled inspection)
• Verify electrical failure
• Fault isolate to replaceable unit
• Perform damage repair
• Perform required remove & replace due to failure

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2.3.2.1 No Shelter Option. Lower level functional flows have been generated for each of the servicing options identified in the introduction. Table 2-9 lists the operational functions for the no shelter option. These start as the OTV rendezvous with the station and proceed through berthing, safing inspection, fault status, scheduled/unscheduled maintenance, payload integration, prelaunch operations, propellant transfer, and launch. The functions with the astrisk are additional ones compared to Table 2-7 in Section 2.3.1.

From the operational functions we derived the element requirements. Table 2-10 lists the element requirements to maintain/service the OTV. The major elements include the maintenance dock, the propellant storage, the control station/maintenance area, the spares storage shelter, and power system interface with the Space Station.

Using the element requirements as the design drivers, we made conceptual layouts of the servicing facilities attached to the Space Station. For the space-based OTV (SBOTV) operational time period, the growth station will be available (see Section 3.8).

Figure 2-7 shows a layout of the no shelter option facilities attached to the station. The SBOTV is shown in the maintenance dock with the manned geostationary mission module attached. This would be the arrangement just prior to launch so that the crew has shirtsleeve ingress to the module from the port on the Multiple Berthing Adapter (MBA).

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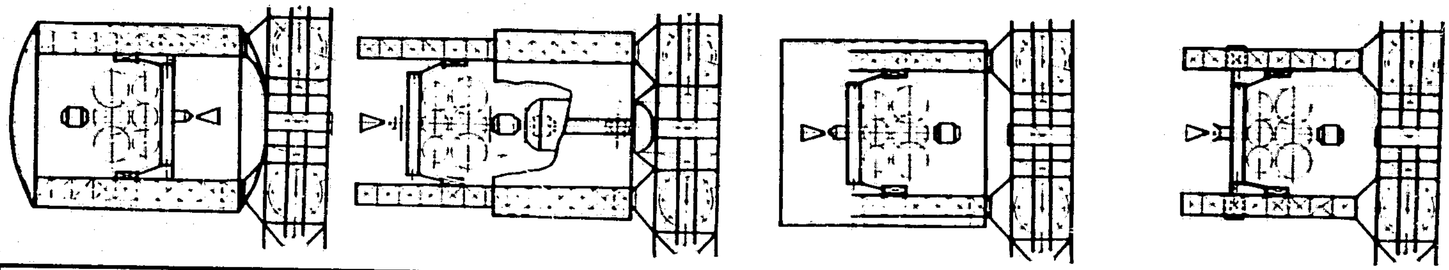

SPACE STATION IMPACT	IVA FULL PRESSURIZED HANGAR	IVA/EVA PRESSURIZED MODULE/SHELTER	EVA SHELTER	EVA NO SHELTER
FACILITIES	• COMPLEX, STATIONARY HANGAR • HANGAR PRESSURE SYSTEM	• PARTIAL OTV ACCESS MODULE • MODULE PRESSURE SYSTEM • SIMPLE MOBILE SHELTER	• SIMPLE MOBILE SHELTER • NO PRESSURE SYSTEM	• NO SHELTER • NO PRESSURE SYSTEM
LIFE SUPPORT SYSTEM	• LARGE VOLUME SYSTEM • 3-5 PSI O_2 WITH COMPLEX AIRLOCK & REPLENISHMENT	• 1/10 HANGAR VOLUME • 14.7 PSI O_2 WITH AIRLOCK & REPLENISHMENT	• EXTRAVEHICULAR MOBILITY UNIT(S)	• EXTRAVEHICULAR MOBILITY UNIT(S)
OTV MAINTENANCE	• SHIRTSLEEVE REPAIR • PROPELLANT SERVICING OUTSIDE HANGAR	• SHIRTSLEEVE & EVA REPAIR • PROPELLANT SERVICING IN PLACE	• ROBOTIC & EVA REPAIR • PROPELLANT SERVICING IN PLACE	• ROBOTIC & EVA REPAIR • PROPELLANT SERVICING IN PLACE
SAFETY	• RESIDUAL PROPELLANT HAZARD • METEORITE & RADIATION PROTECTION	• RESIDUAL PROPELLANT HAZARD • METEORITE & RADIATION PROTECTION	• RESIDUAL PROPELLANT SAFE • METEORITE & RADIATION PROTECTION	• RESIDUAL PROPELLANT SAFE • NO ENVIRONMENT PROTECTION
GROWTH POTENTIAL	• DIFFICULT ADD-ON	• SIMPLE ADD-ON	• SIMPLE ADD-ON	• EASY ADD-ON
COST	• HIGH COST	• MEDIUM COST	• LOWER COST	• LOWER COST

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Figure 2-6. Maintenance Facility Evaluation

Table 2-9. Space-Based OTV Operational Functions, No Shelter

BERTH OTV
- RENDEZVOUS OTV WITH STATION
- CAPTURE OTV AT STATION
- BERTH OTV IN MAINTENANCE DOCK*

TRANSFER PROPELLANT
- VERIFY INTERFACE INTEGRITY
- PERFORM PROPELLANT LEAK CHECK
- TRANSFER RESIDUAL PROPELLANT FROM OTV TO STATION

INSPECT OTV
- PERFORM VISUAL INSPECTION
  - TV INSPECTION*
- DETERMINE OTV FAULT STATUS
- WHEN FAULT OR DAMAGE DETECTED
  - PERFORM DAMAGE ASSESSMENT (TV/EVA)
  - INITIATE ELECTRICAL TEST ROUTINE TO VERIFY FAULT
  - INITIATE FAULT ISOLATION ROUTINE
- FORMULATE INTEGRATED MAINTENANCE PLAN

PERFORM OTV MAINTENANCE
- PERFORM SCHEDULED/UNSCHEDULED MAINTENANCE TASKS
- MISSION RECONFIGURE
- PERFORM SYSTEM OPERATIONAL TESTING
- DEACTIVATE & STOW OTV (IF NOT REQUIRED FOR MISSION AT THIS TIME)

MATE OTV & PAYLOAD
- ROTATE OTV FOR PAYLOAD INTEGRATION*
- TRANSFER PAYLOAD TO OTV
- MATE PAYLOAD TO OTV
- VERIFY OTV/PAYLOAD INTERFACE
- PERFORM OTV/PAYLOAD INTEGRATION TEST

LAUNCH OTV/PAYLOAD
- PERFORM PRELAUNCH OPERATIONS
- TRANSFER PROPELLANT FROM STATION TO OTV
- LAUNCH OTV/PAYLOAD

*FUNCTIONS PECULIAR TO CONCEPT

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Table 2-10. OTV Maintenance Facility (No Shelter Configuration) Element Requirements

---

- o Maintenance dock
  - Main truss support structure
  - OTV berthing interface, structure, and translating and rotating mechanism
  - Electrical interconnects between berthing interface, control, and power source
  - Fluid lines from quick disconnect panel to propellant storage control interface
  - Lighting installation
  - Electrical interconnects between lights and maintenance dock interface
  - Handling device to provide EVA mobility and restraint, equipped with TV system and communications - RMS/robotic capability (this may become an adapter to the RMS)
  - Electrical interconnects betweeen handling device and maintenance dock interface
  - RMS support with rails/tracks
  - RMS including TV, lights, end effector/tool adapter
  - Electrical interconnects between RMS and maintenance dock interface
  - Tool storage fixture for handling device/robotics and RMS

- o Propellant storage
  - Main support structure
  - Hydrogen storage tank
  - Oxygen storage tank
  - o Control and interface unit, valves, controls, etc.
  - Fluid lines from tanks to control interface
  - Refrigeration unit and plumbing
  - Electrical interconnects between control unit, refrigeration unit, maintenance module and power source
  - Radiators

- o Control Station/maintenance area
  - Pressurized compartment
  - Airlock for EVA operations (serves as observation module)
  - General purpose computer system
  - Dedicated control equipment including OTV docking, berthing, and handling
  - Communications and data links
  - Observation and inspection equiment monitors (includes TV, propellant sensors)
  - Tools, maintenance and check out equipment and maintenance area
  - Pressurized hatch for IVA regress/egress to manned GEO mission module

Table 2-10. OTV Maintenance Facility (No Shelter Configuration) Element Requirements, Contd

- o Spares storage shelter
  - Spare parts storage platform or holding fixtures with lights to contain avionics ORUS, ACS module spares, an engine, three tank modules and a manned GEO mission module
- o Electrical power system (main station asset)
  - Power generation system
  - Power control and distribution system
  - Maintenance facility interface

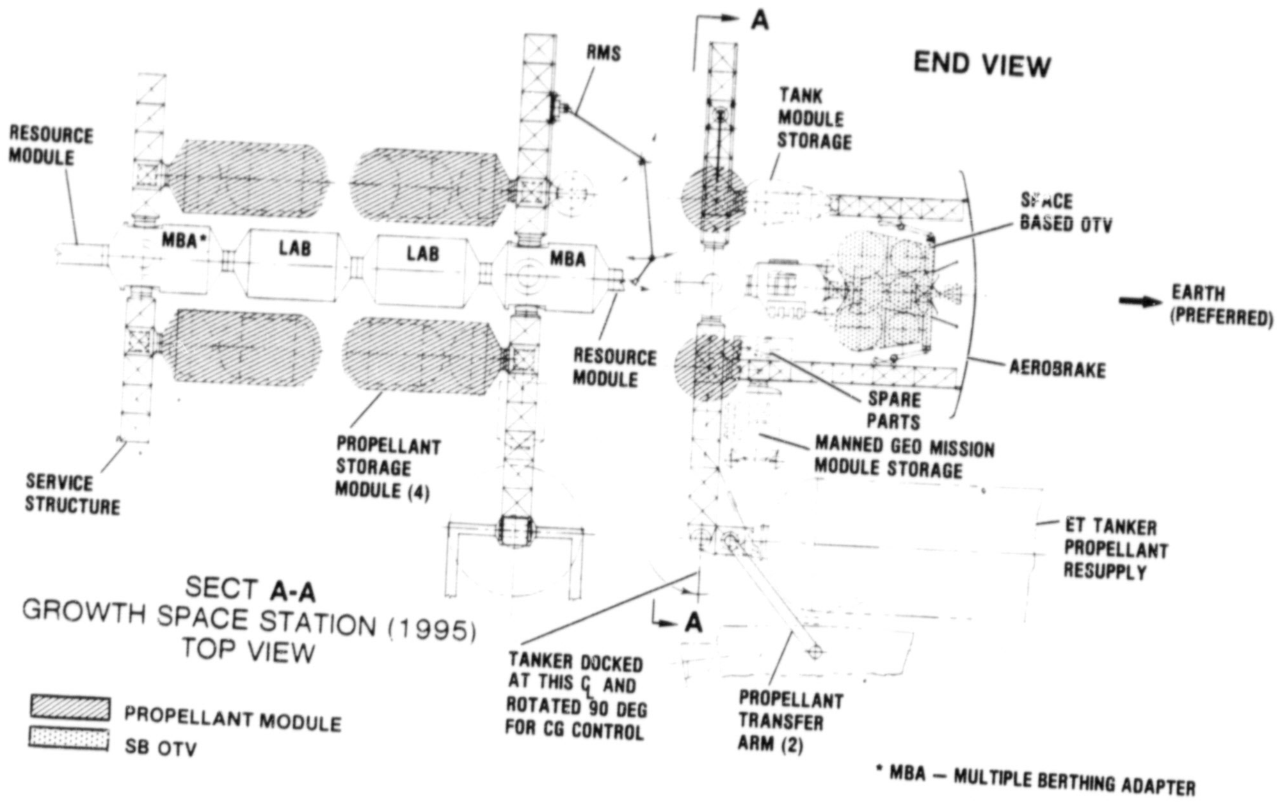

Figure 2-7. OTV Maintenance Facility - No Shelter Option

The crewmen would use the airlock on the MBA to access the OTV for maintenance. The docking, berthing, and maintenance equipment are attached to the two main support trusses. With no shelter, the micrometeoroid and debris protection requirements imposed upon the OTV are much more severe than with a shelter and can affect its mass fraction adversely. The preferred orientation of the maintenance dock is shown to minimize debris problems. The four propellant storage modules are shown attached to the service structure close to the laboratory modules to place them near the station center of gravity (cg) and close to the OTV. To support the OTV traffic postulated for the late 1990s, an external tank (ET) tanker is required to resupply propellant. The tanker is shown docked to the end of the service structure. The tanker would dock to the centerline of the service structure but may have to be rotated 90 degrees for cg control purposes. The OTV control station would most probably be in the MBA. The question of how much pressurized maintenance volume is required is still to be resolved. Provision for spare parts storage is shown in unpressurized areas.

2.3.2.2 Shelter Option. Table 2-11 lists the operational functions for the shelter option. These start with the OTV rendezvous with the station and proceed through berthing, safing, inspection, fault status, scheduled/unscheduled maintenance, payload integration, prelaunch operations, propellant transfer, and launch. Some shelter operations are also included in the overall sequence. The functions with the asterisk are additional ones compared to Table 2-7 in Section 2.3.1.

Table 2-12 identifies the element requirements to maintain/service the OTV. The major elements include the maintenance dock, maintenance shelter, propellant storage, control station/maintenance area, the spares storage shelter, and power system interface with the Space Station. With the addition of the shelter, many of the maintenance support equipment items are now placed on the shelter for more efficient operation compared to the previous option without the shelter.

Figure 2-8 shows a layout of the shelter option facilities attached to the station. The SBOTV is shown attached to the end of the maintenance dock located in a position to receive a payload, in this case the manned geostationary crew module. For maintenance and storage the SBOTV, detached from the aerobrake, can be moved up under the shelter. The shelter protects the SBOTV from micrometeoroids and space debris while residing at the station. The preferred orientation for the service facilities is indicated.

The crewmen would use the airlock on the MBA to access to OTV for maintenance. Docking, berthing, and some maintenance equipment are attached to the two main support trusses. Other maintenance and handling equipment, such as a remote manipulator system (RMS) for handling payloads, are attached to the shelter along with provisions to store the manned geostationary module and three sets of tank modules. One set is a spare and the other two are to be added to the payload delivery only SBOTV mission configuration for the manned missions. The four propellant storage modules are shown attached to the service structure as in the previous concept. In addition, the ET tanker is shown docked to the end of the service structure. The OTV control station would most probably be in the MBA. Again the question of how much pressurized maintenance volume is required is still to be resolved.

Table 2-11. Space-Based OTV Operational Functions - Shelter Option

Berth OTV
- Rendezvous OTV with station
- Capture OTV at station
- Berth OTV in maintenance dock*
- Extend shelter to cover OTV*

Transfer propellant
- Verify interface integrity
- Perform propellant leak check
- Transfer residual propellant from OTV to station

Inspect OTV
- Perform visual inspection
  - TV inspection*
- Determine OTV fault status
- When fault or damage detected
  - Perform damage assessment (TV/EVA)
  - Initiate electrical test routine to verify fault
  - Initiate fault isolation routine
- Formulate integrated maintenance plan

Perform OTV maintenance
- Perform scheduled/unscheduled maintenance tasks
- Mission Reconfigure
- Perform system operational testing
- Deactivate & stow OTV (if not required for mission at this time)

Mate OTV & payload
- Retract OTV shelter*
- Rotate OTV for payload integration*
- Transfer payload to OTV
- Mate payload to OTV
- Verify OTV/payload interface
- Perform OTV/payload integration test

Launch OTV/payload
- Perform prelaunch operations
- Transfer propellant from station to OTV
- Launch OTV/payload

*Functions peculiar to concept

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2.3.2.3 Shelter/Maintenance Module Option. Table 2-13 lists the operational functions for the maintenance module option. These start with the OTV rendezvous with the station and proceed through berthing, safing, inspection, fault status, placement of either or both ends of OTV in the maintenance module, scheduled/unscheduled maintenance, payload integration, prelaunch operations, propellant transfer, and launch. The functions with the asterisks are additional ones compared to Table 2-7 in Section 2.3.1.

Table 2-12. OTV Maintenance Facility (Shelter Configuration) Element Requirements

Maintenance dock
- Main truss support structure
- OTV berthing interface, structure & translating & rotating mechanism & carriage
- Electrical interconnects between berthing interface, maintenance module & power source interface
- Fluid lines from quick disconnect panel to propellant storage control interface
- Support structures for shelter
- Rail/track system for shelter & berthing carriage
- Electrical interconnects between shelter interface, maintenance control station & power source interface
- Handling device to provide EVA mobility & restraint, equipped with TV system & communications; RMS/robotic capability
- Electrical interconnects between handling device & maintenance dock interface

Spares storage shelter
- Spare parts storage platform or holding fixtures with lights to contain avionics ORUs, ACS module spares, an engine, three tank modules & a manned GEO crew module

Maintenance shelter
- Main shelter structure
- Shelter to maintenance dock structure rail/track interface
- Shelter mobility control motors
- Lighting installation
- Electrical interconnects between lights & maintenance dock interface
- Exterior RMS support with rails/tracks
- RMS including TV, lights, end effector/tool adapter
- Electrical interconnects from RMS to maintenance dock interface
- Tool storage fixture for handling device/robotics & RMS
- Possible antenna installations

Electrical power system (main station asset)
- Power generation system
- Power control & distribution system
- Maintenance facility interface

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Table 2-12. OTV Maintenance Facility (Shelter Configuration) Element Requirements, Contd

Propellant storage

- Main support structure
- Hydrogen storage tank
- Oxygen storage tank
- Control & interface unit, valves, controls, etc
- Fluid lines from tanks to control interface
- Refrigeration unit & plumbing
- Electrical interconnects between control unit, refrigeration unit, maintenance module & power source
- Radiators

Control station maintenance area

- Pressurized compartment
- Airlock for EVA operations (serves as observation station)
- General purpose computer system
- Dedicated control equipment including OTV docking, berthing & handling
- Communications & data links
- Observation & inspection equipment monitors (include TV, propellant sensors)
- Tools, maintenance & checkout equipment & maintenance area
- Pressurized hatch for IVA ingress/egress to manned GEO crew module

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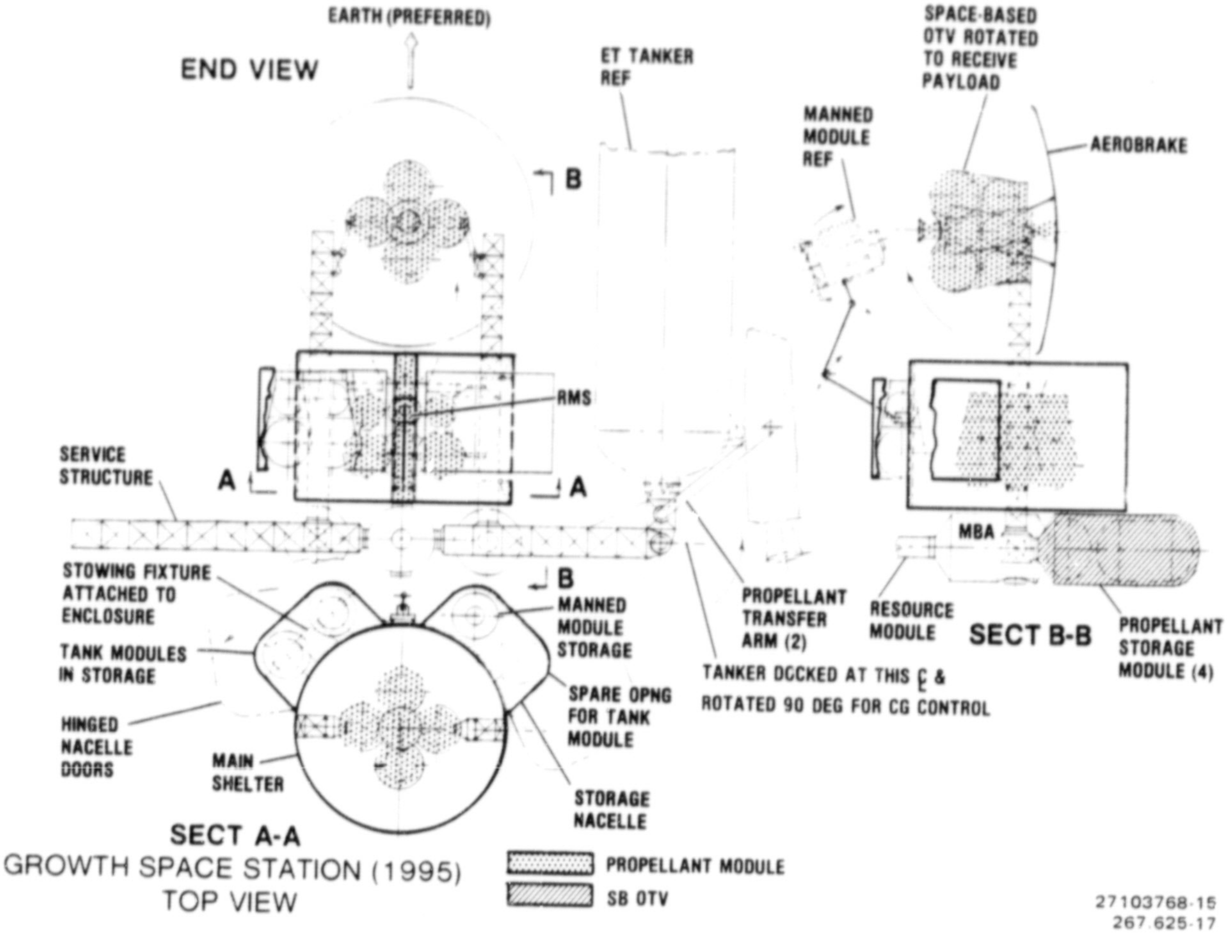

Figure 2-8. OTV Maintenance Facility - Shelter Option

Table 2-14 identifies the element requirements to maintain/service the OTV. The major elements include the maintenance dock, maintenance shelter, propellant storage, maintenance module/control station, spares storage shelter, and power system interface with the Space Station. The maintenance module can enclose both ends of the OTV for shirtsleeve maintenance on the avionics modules and the engine after the aerobrake has been detached. This requires a pressurizable bulkhead on both ends of the OTV in the appropriate position. Again the OTV is protected by the movable shelter against micrometeoroids and space debris. The avionics modules and engine modules can be worked on in a shirtsleeve environment, but the other components on the OTV, such as tank modules, aerobrake, etc., must be worked on by EVA.

Table 2-13. Space-Based OTV Operational Functions for the Maintenance Module Option

BERTH OTV

- RENDEZVOUS OTV WITH STATION
- CAPTURE OTV AT STATION
- BERTH OTV IN MAINTENANCE DOCK*
- EXTEND SHELTER TO COVER OTV*

TRANSFER PROPELLANT

- VERIFY INTERFACE INTEGRITY
- PERFORM PROPELLANT LEAK CHECK
- TRANSFER RESIDUAL PROPELLANT FROM OTV TO STATION

INSPECT OTV

- PERFORM VISUAL INSPECTION
  - TV INSPECTION*
- DETERMINE OTV FAULT STATUS
- WHEN FAULT OR DAMAGE DETECTED
  - PERFORM DAMAGE ASSESSMENT (TV/EVA)
  - INITIATE ELECTRICAL TEST ROUTINE TO VERIFY FAULT
  - INITIATE FAULT ISOLATION ROUTINE
- FORMULATE INTEGRATED MAINTENANCE PLAN

MATE OTV WITH MAINTENANCE MODULE

- DE-PRESSURIZE MODULE*
- OPEN MODULE HATCH*
- PLACE APPROPRIATE END OF OTV IN MAINTENANCE MODULE*
- CHECK PRESSURE SEAL*
- PRESSURIZE MODULE*
- ALLOW PERSONNEL TO ENTER MODULE*

PERFORM OTV MAINTENANCE

- PERFORM SCHEDULED/UNSCHEDULED MAINTENANCE TASKS
- MISSION RECONFIGURE
- PERFORM SYSTEM OPERATIONAL TESTING

DEMATE OTV FROM MAINTENANCE MODULE

- EXIT PERSONNEL FROM MODULE*
- DEPRESSURIZE MODULE*
- REMOVE OTV*
- EITHER CLOSE MODULE HATCH OR EXCHANGE ENDS OF OTV IN MAINTENANCE MODULE WHEN APPROPRIATE*
- REPEAT PRESSURIZATION TASKS*
- FULLY PRESSURIZE MODULE*
- CHECK MODULE ENVIRONMENT*
- ALLOW PERSONNEL TO ENTER MODULE*
- DEACTIVATE & STOW OTV (IF NOT REQUIRED FOR MISSION AT THIS TIME)

MATE OTV & PAYLOAD

- RETRACT OTV SHELTER*
- ROTATE OTV FOR PAYLOAD INTEGRATION*
- TRANSFER PAYLOAD TO OTV
- MATE PAYLOAD TO OTV
- VERIFY OTV/PAYLOAD INTERFACE
- PERFORM OTV/PAYLOAD INTEGRATION TEST

LAUNCH OTV/PAYLOAD

- PERFORM PRELAUNCH OPERATIONS
- TRANSFER PROPELLANT FROM STATION TO OTV
- LAUNCH OTV/PAYLOAD

*FUNCTIONS PECULIAR TO CONCEPT

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Table 2-14. OTV Maintenance Facility Element Requirements for Pressurized OTV Maintenance Module/Shelter Configuration

- o Maintenance dock
  - Main truss support structure
  - OTV berthing interface, structure, and translating and rotating mechanism & carriage
  - Electrical interconnects between berthing interface, maintenance module & power source interface
  - Fluid lines from quick disconnect panel to propellant storage control interface
  - Support structures for shelter
  - Rail/track system for shelter & berthing carriage
  - Electrical interconnects between shelter interface, maintenance module & power source interface
  - Handling device to provide EVA mobility & restraint, equipped with TV system & communications RMS/robotic capability
  - Electrical interconnects between handling device and maintenance dock interface

- o Maintenance shelter
  - Main shelter structure
  - Shelter to maintenance dock structure rail/track interface
  - Shelter mobility control motors
  - Lighting installation
  - Electrical interconnects between lights & maintenance dock interface
  - Exterior RMS support with rails/tracks
  - RMS including TV, lights, end effector/tool adapter
  - Electrical interconnects from RMS to maintenance dock interface
  - Tool storage fixture for handling device/robotics & RMS
  - Possible antenna installations

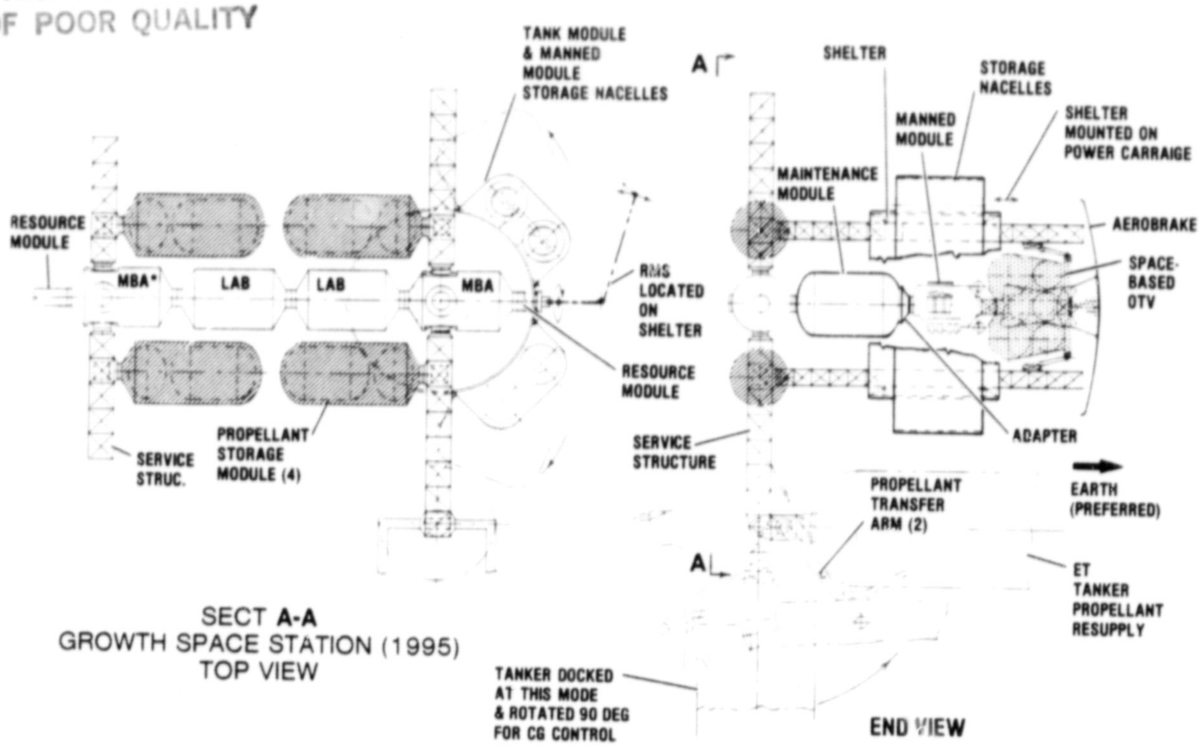
- o Propellant storage
  - Main support structure
  - Hydrogen storage tank
  - Oxygen storage tank
  - Control & interface unit, valves, controls, etc.
  - Fluid lines from tanks to control interface
  - Refrigeration unit & plumbing
  - Electrical interconnects between control unit, refrigeration unit, maintenance module & power source
  - Radiators

Table 2-14. OTV Maintenance Facility Element Requirements for Pressurized OTV Maintenance Module/Shelter Configuration, Contd

- o Maintenance module/control station (standard module)
  - Pressurized compartment
  - Airlock for EVA operations (serves as observation module)
  - Pressurized hatch & OTV interface
  - General purpose computer system
  - Dedicated control equipment including OTV docking, berthing and handling
  - Communications & data links
  - Observation & inspection equipment monitors (include TV, propellant sensors)
  - Tools, maintenance and check out equipment and maintenance area
  - Pressurized hatch for IVA regress/egress to manned mission module
  - Spare parts storage volume to contain avionics ORUS, an engine, etc.
- o Spares storage shelter
  - Spare parts storage platform and holding fixtures with lights to contain three tank modules and a manned GEO mission module
- o Electrical power system (main station asset)
  - Power generation system
  - Power control & distribution system
  - Maintenance facility interface

Figure 2-9 shows a layout of the shelter/maintenance module facilities attached to the station. The SBOTV is shown in the maintenance dock with the manned geostationary mission module attached. This would be the arrangement just prior to launch so that the crew has shirtsleeve ingress to the module from the maintenance module. The second part of Figure 2-9 shows the SBOTV during the maintenance operation with the avionics modules inside the maintenance module for shirtsleeve access. The aerobrake is shown detached and stowed on the maintenance dock truss structure. The shelter is positioned over the SBOTV for protection. The SBOTV engine can also be placed in the maintenance module for shirtsleeve access.

The maintenance module is a standard Space Station module with a special opening on one end to accept and seal the pressure bulkhead on the SBOTV. For the required EVA the crewmen would use the airlock on the MBA. Some of the maintenance equipment that was on the maintenance dock and shelter in the previous concepts is inside the maintenance module. However, capability to support and move EVA crewmen, change out or add tank modules, and integrate paylods must still be provided on the maintenance dock and shelter. The maintenance module can contain the control station and pressurized maintenance volume. A space engine and avionics modules can be stored inside the maintenance module, but the extra tank modules and manned modules are stored on the shelter as in the previous concept. The four propellant storage modules are shown attached to the service structure as in the previous concepts. In addition, the ET tanker is shown docked to the end of the service structure as before.



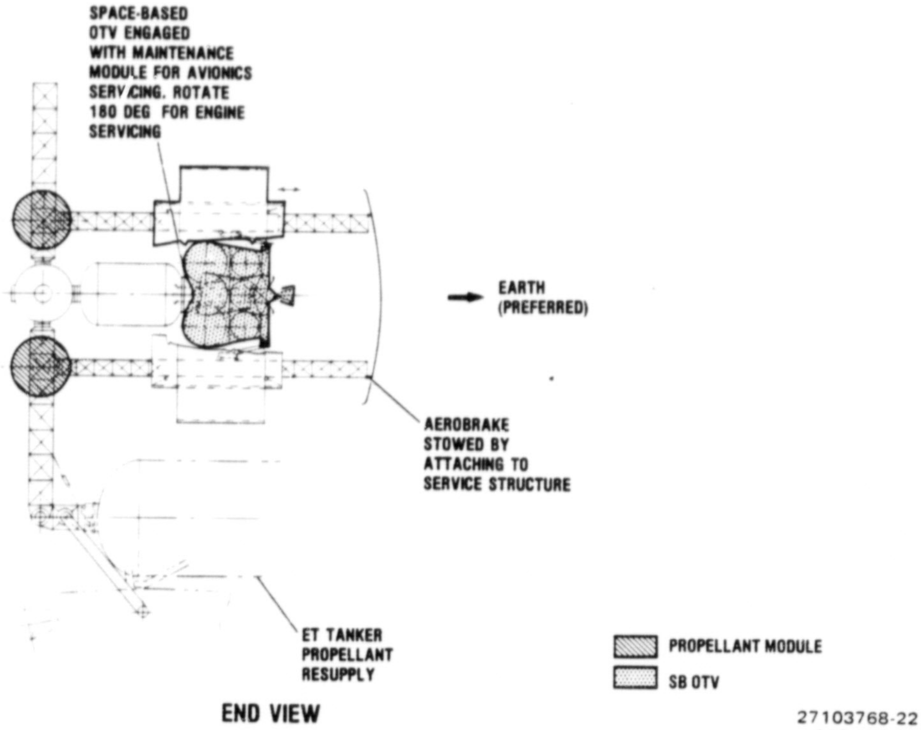


Figure 2-9. OTV Maintenance Facility - Maintenance Module Option

2.3.2.4 <u>Pressurized Hangar Option</u>. Table 2-15 lists the operational functions for the pressurized hangar option. These start with preparing the hangar for the OTV, and the OTV rendezvous with the station. They then proceed through berthing, safing, inspection, fault status, pressurizing the hangar, scheduled/unscheduled maintenance, depressurization of the hangar, payload integration, prelaunch operations, propellant transfer, and launch.

Table 2-16 identifies the element requirements to maintain/service the OTV. The major elements include the maintenance hangar, control station, maintenance dock, propellant storage, spares storage area, and power system interface with the Space Station. In this concept the total OTV including the aerobrake is enclosed in the pressurized hangar. All maintenance activities are conducted in a pressurized environment. The only possible EVA would occur if something went wrong with deploying appendages on a payload after mating with the OTV and could be fixed by a crewman without demating. This operation is accomplished outside the hangar. We still need a separate pressurized control station for the OTV activities that must be controlled while the hangar door is open such as rendezvous, docking, berthing, payload integration, propellant transfer, etc.

Figure 2-10 shows a layout of the pressurized hangar facility. It is only a line drawing of a possible envelope to encompass the OTV including the aerobrake. The actual configuration for a hangar brought up in the Shuttle and assembled on orbit would be much more complicated. This is a good subject for the Boeing Large Space Structures TDM study.

The OTV is shown inside the hangar with the crew module for shirtsleeve ingress from the MBA. During the maintenance operations, the crewmen would enter the hangar from the MBA. All the maintenance activities take place within the pressurized hangar. All the spare parts including the crew module are stored within the hangar. Figure 2-10 shows where the hangar door must be placed so that the OTV can be rotated for integration of large payloads with deployable appendages.

The control station can be housed in the MBA. The airlock on the MBA can be used for an EVA fix on a payload with large appendages that has been integrated with the OTV. The four propellant storage modules are shown attached to the service structure as in the previous concepts. In addition, the ET tanker is shown docked to the end of the service structure as before.

2.3.2.5 <u>Separate Propellant Depot Option</u>. Figure 2-11 shows the top level functional flow for the separate propellant depot. It differs from the previous ones in that the OTV must visit the propellant depot on returning from a mission to detank any residual propellants before it visits the station. In addition, the OTV must visit the propellant depot after maintenance and payload integration is accomplished at the station to be loaded with propellant for the mission.

Table 2-15. Space-Based OTV Operational Functions for Pressurized Hangar Option

BERTH OTV
- PUMP DOWN HANGAR*
- OPEN HANGAR DOOR*
- RENDEZVOUS OTV WITH STATION
- CAPTURE OTV AT STATION
- BERTH OTV IN MAINTENANCE DOCK*

TRANSFER PROPELLANT
- VERIFY INTERFACE INTEGRITY
- PERFORM PROPELLANT LEAK CHECK
- TRANSFER RESIDUAL PROPELLANT FROM OTV TO STATION

INSPECT OTV
- PERFORM VISUAL INSPECTION
  - TV INSPECTION*
- DETERMINE OTV FAULT STATUS
- WHEN FAULT OR DAMAGE DETECTED
  - PERFORM DAMAGE ASSESSMENT
  - INITIATE ELECTRICAL TEST ROUTINE TO VERIFY FAULT
  - INITIATE FAULT ISOLATION ROUTINE
- FORMULATE INTEGRATED MAINTENANCE PLAN

PRESSURIZE HANGAR
- CLOSE HANGAR DOOR AND SEAL*
- PARTIALLY PRESSURIZE HANGAR*
- CHECK PRESSURE INTEGRITY*
- FULLY PRESSURIZE HANGAR*
- CHECK HANGAR ENVIRONMENT*
- ALLOW PERSONNEL TO ENTER HANGAR*

PERFORM OTV MAINTENANCE
- PERFORM SCHEDULED/UNSCHEDULED MAINTENANCE TASKS
- MISSION RECONFIGURE
- PERFORM SYSTEM OPERATIONAL TESTING
- DEACTIVATE & STOW OTV (IF NOT REQUIRED FOR MISSION AT THIS TIME)

DE-PRESSURIZE HANGAR & RETRACT OTV
- EXIT PERSONNEL FROM HANGAR*
- DE-PRESSURIZE HANGAR (PUMP DOWN)*
- OPEN HANGAR DOOR*
- RETRACT OTV FROM HANGAR*

MATE OTV & PAYLOAD
- ROTATE OTV FOR PAYLOAD INTEGRATION*
- TRANSFER PAYLOAD TO OTV
- MATE PAYLOAD TO OTV
- VERIFY OTV/PAYLOAD INTERFACE
- PERFORM OTV/PAYLOAD INTEGRATION TEST

LAUNCH OTV/PAYLOAD
- PERFORM PRELAUNCH OPERATIONS
- TRANSFER PROPELLANT FROM STATICN TO OTV
- LAUNCH OTV/PAYLOAD

*FUNCTIONS PECULIAR TO CONCEPT

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Table 2-16. OTV Maintenance Facility Element Requirements for Pressurized Hangar Option

- o Maintenance hangar, pressurized
  - Hangar interface support structure
  - Main hangar structure
  - Truss support for maintenance dock
  - Main hangar door & seal system
  - Main hangar door control motors & mechanisms
  - Aerobrake holding fixture on door
  - Personnel access door
  - Hangar pressurization system
  - Environmental control system (pressure, humidity, temperature, contamination)
  - Lighting installation
  - Crane support with rails/tracks
  - Crane with attachment fixtures
  - Handling device to provide crewmen mobility and restraint equipped with TV system and communications RMS/robotic capability
  - Tools, maintenance and check out equipment
  - Spare parts storage compartments or holding fixtures to contain avionics ORUS, ACS module spares, an engine, three tank modules & a manned GEO mission module
  - Antenna installations on exterior hangar
  - Maintenance dock truss extender control motors
  - Electrical interconnects

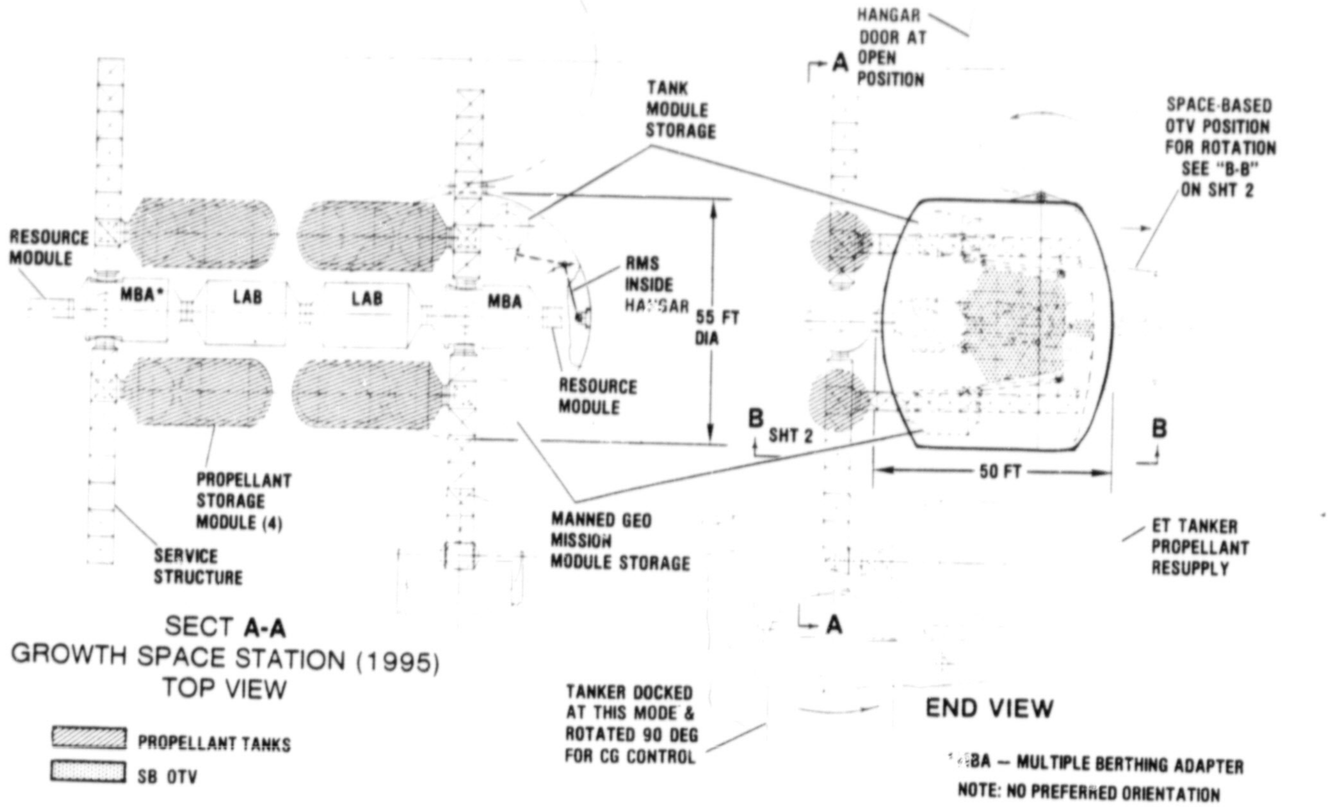
- o Control station
  - Pressurized compartment
  - General purpose computer system
  - Dedicated control equipment including OTV, docking, berthing and handling
  - Observation & inspection equipment monitors (including TV, propellant sensors)
  - Communication data lines system with caution & warning
  - Airlock for EVA operations (payload)

- o Maintenance dock (interior)
  - Main truss support structure
  - OTV berthing interface, structure & translating & rotating mechanism and carriage
  - Rail/tracks system for berthing carriage
  - Electrical interconnects between berthing interface, hangar, & power source interface
  - Fluid lines from quick disconnect panel to propellant storage control interace

- o Space station or hangar exterior RMS
  - Structure, controls, lights, TV, etc.

Table 2-16. OTV Maintenance Facility Element Requirements for Pressurized Hangar Option, Contd

- o Spares storage area
  - Spare parts storage platform or holding fixtures to contain avionics ORUS, ACS module spares, an engine, three tank modules and a manned GEO mission module
- o Propellant storage
  - Main support structure
  - Hydrogen storage tank
  - Oxygen storage tank
  - Control & interface unit, valves, controls, etc.
  - Fluid lines from tanks to control interface
  - Refrigeration unit & plumbing
  - Electrical interconnects between control unit, refrigeration unit, maintenance module & power source
  - Radiators
- o Electrical power system (space station asset)
  - Power generation system
  - Power control & distribution system
  - Maintenance facility interface



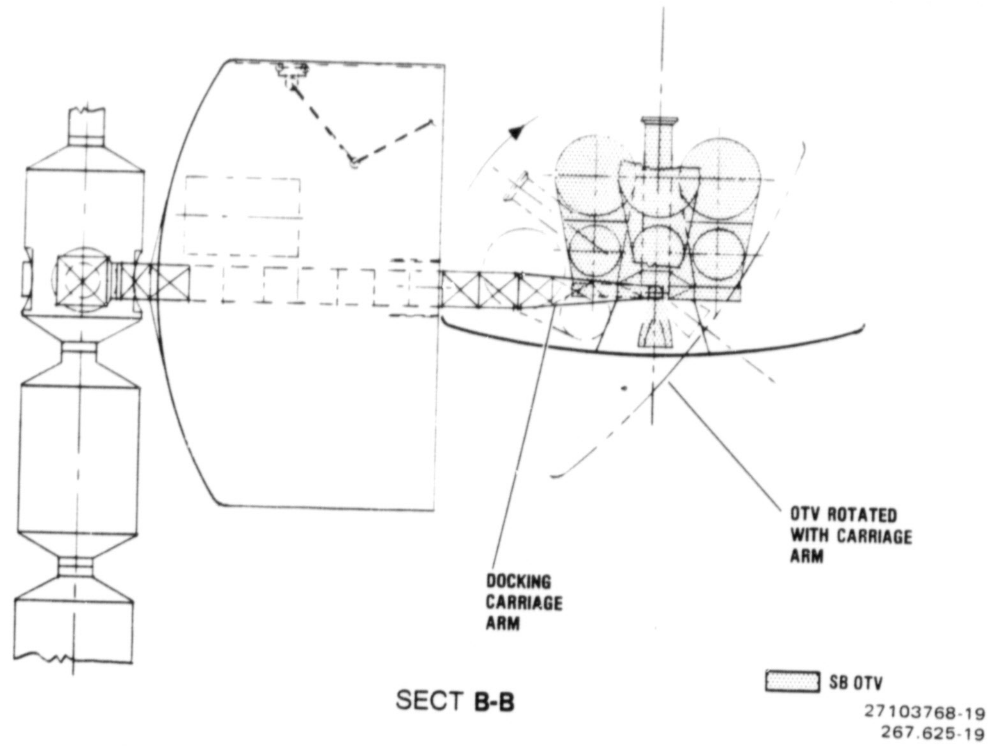


Figure 2-10. OTV Maintenance Facility - Pressurized Hangar Option

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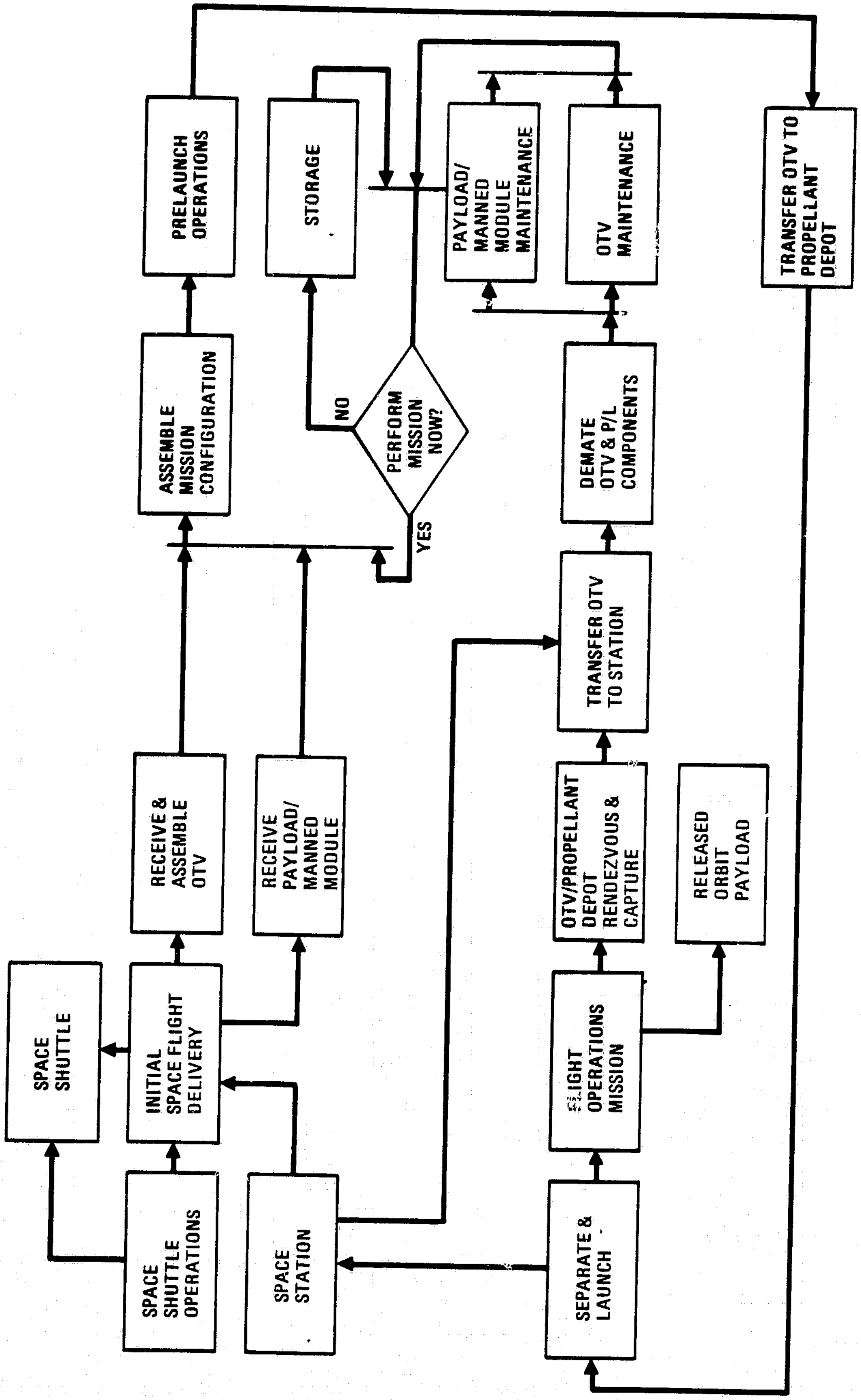

Figure 2-11. Space-Based OTV Operations for Separate Propellant Depot

Table 2-17 lists the lower level operational functions for the separate propellant depot option. A separate depot can be used with any of the previous maintenance options. For illustrative purposes we have chosen to discuss it in conjunction with the shelter maintenance facility. These functions start with the OTV rendezvous and docking with the propellant depot after completing its missions. The functions then proceed through transferring the residual fuel from the OTV to the depot to transferring the OTV from the depot to the Space Station. The functions to be performed at the Space Station are the same as described in Section 2.2.2 except for the propellant loading. After mating and checking out the payload, the OTV is transferred to the propellant depot for fueling before launch for the mission.

Table 2-18 lists the element requirements to maintain and service the OTV with shelter facilities on the stationa and separate propellant depot. The major elements include the maintenance dock, maintenance shelter, control station/maintenance area, spares storage shelter, and the power system interface with the Space Station. These facilities are attached to the station. In addition, the separate propellant depot must have a main facility structure, which houses the subsystems to support the facility, a cryogenic propellant storage facility, and a docking and berthing capability for the OTV. These requirements are listed in Table 2-19.

Figure 2-12 is a layout of the separate propellant depot. It shows the main facility structure with the four propellant storage modules attached and the major subsystems to support the facility. Also shown is the docking and propellant transfer mechanisms for both the OTV and the ET tanker. The ET tanker docking and propellant transfer arrangement is very similar to the one shown for the Space Station. The OTV must be able to obtain propellants with a large payload attached with multiple appendages.

Figure 2-13 is a layout of the maintenance module facilities on the station without the propellant storage modules and the ET tanker docking provisions. This eliminates considerable mass from the station, which has to be balanced and controlled, and the hazards of a propulsive thrust due to a tank rupture from space debris.

We considered the option of performing maintenance on the OTV on the propellant depot but rejected it. This option requires all the maintenance facilities to be on the propellant depot, which could be an advantage to the station but it requires the crew to be transported back and forth from the station to the depot. This later operation we feel is not desirable and makes the whole operation quite complex and possibly hazardous. The OTV must either come to the Space Station for the payload or the payload transported to the depot. Since this transfer operation must be performed, GDC felt that the most effective operation is to perform the maintenance at the station.

Table 2-17. Space-Based OTV Operational Functions for Separate Propellant Depot Option (with Shelter Facility)

Berth OTV in propellant depot
- Rendezvous OTV with depot
- Capture OTV at depot
- Berth OTV in propellant transfer dock

Transfer propellant to depot
- Verify interface integrity
- Perform propellant leak check
- Transfer propellant from OTV to depot
- Release OTV from depot berthing

Transfer OTV from depot to station using OMV

Berth OTV at space station
- Capture OTV at station
- Berth OTV in maintenance dock
- Verify interface integrity

Inspect OTV
- Perform visual inspection
  - TV inspection
- Determine OTV fault status
- When fault or damage detected
  - Perform damage assessment (TV/EVA)
  - Initiate electrical test routine to verify fault
  - Initiate fault isolation routine

Perform OTV maintenance
- Formulate integrated maintenance plan
- Perform scheduled/unscheduled maintenance tasks
- Perform system operational testing
- Deactivate & stow OTV (if not required for mission at this time)

Mate OTV & payload
- Rotate OTV for payload integration
- Transfer payload to OTV
- Mate payload to OTV
- Verify OTV/payload interfaces
- Perform OTV/payload integration test

Transfer OTV from station to depot

Berth OTV in propellant depot
- Capture OTV at depot
- Berth OTV in propellant transfer dock
- Verify interface integrity

Launch OTV/payload
- Perform prelaunch operations
- Transfer propellant from depot to OTV
- Launch OTV/payload from propellant depot

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Table 2-18. OTV Maintenance Facility Element Requirements for Shelter Configuration with Separate Free-Flying Propellant Depot

- o Maintenance dock
  - Main truss support structure
  - OTV berthing interface, structure, and translating and rotating mechanism & carriage
  - Electrical interconnects between berthing interface, maintenance module & power source interface
  - Support structures for shelter
  - Rail/track system for shelter & berthing carriage
  - Electrical interconnects between shelter interface, maintenance control station & power source interface
  - Handling device to provide EVA mobility & restraint, equipped with TV system & communications; RMS/robotic capability
  - Electrical interconnects between handling device & maintenance dock interface

- o Maintenance shelter
  - Main shelter structure
  - Shelter to maintenance dock structure rail/track interface
  - Shelter mobility control motors
  - Lighting installation
  - Electrical interconnects between lights & maintenance dock interface
  - Exterior RMS support with rails/tracks
  - RMS including TV, lights, end effector/tool adapter
  - Electrical interconnects from RMS to maintenance dock interface
  - Tool storage fixture for handling device/robotics & RMS
  - Possible antenna installations

- o Control station/maintenance area
  - Pressurized compartment
  - Airlock for EVA operations (serves as observation station)
  - General purpose computer system
  - Dedicated control equipment including OTV docking, berthing and handling
  - Communications & data links
  - Observation & inspection equipment monitiors (include TV, propellant sensors)
  - Tools, maintenance and check out equipment and maintenance area
  - Pressurized hatch for IVA regress/egress to manned GEO mission module

- o Spares storage shelter
  - Spare parts storage platform or holding fixtures with lights to contain avionis ORUS, ACS module spares, an engine, three tank modules and a manned GEO mission module

- o Electrical power system (main station asset)
  - Power generation system
  - Power control & distribution system
  - Maintenance facility interface

Table 2-19. Separate Propellant Facility Element Requirements

- o Main facility structure
  - Power generating & storage system
  - Power distribution system
  - RCS & station keeping equipment including necessary structures
  - RCS propellant storage
  - Control avionics
  - Antennas
  - Lighting installation
  - TV system
  - Electrical interconnections
- o Cryogenic propellant storage
  - Main support structure
  - Hydrogen storage tank
  - Oxygen storage tank
  - Control & interface unit, valves, controls, etc.
  - Fluid lines from tanks to control interface
  - Refrigeration unit & plumbing
  - Radiators
  - Electrical interconnects between control unit, refrigeration unit & power source
  - Propellant condition monitoring equipment
- o OTV dock mechanism
  - Dock structure
  - OTV berthing interface
  - Fluid lines from quick disconnect panel to propellant storage control interface

2.3.3 PROPELLANT TRANSPORTATION TO LEO. Our Space Station study (Reference 4) showed that to achieve the greatest economic benefits for a space-based OTV the propellants must be brought to LEO in something other than the Shuttle cargo bay. In the first years of operation of the SBOTV, propellant scavenging from the ET can provide the lower cost propellant. However, starting in the mid 90s the traffic rate is such that propellant scavenging will not provide the required amount. Another method of transporting propellant needs to be provided such as the ET tanker. The following data was developed in our Space Station study and is presented here to indicate the technology requirements to be developed to resupply cryogenic propellants to LEO in a cost effective manner.

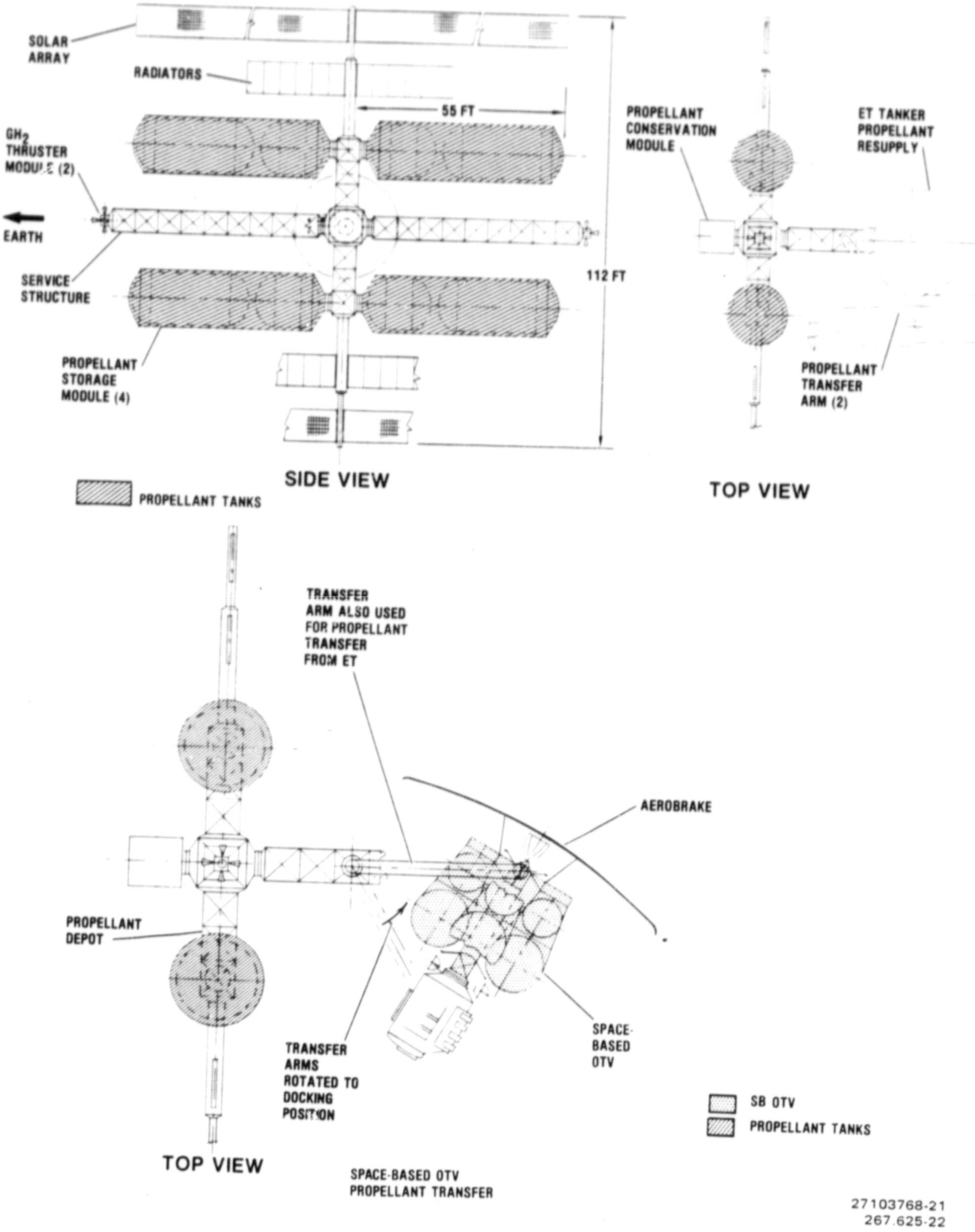

Figure 2-12. OTV Maintenance Facility - Separate Propellant Depot Option

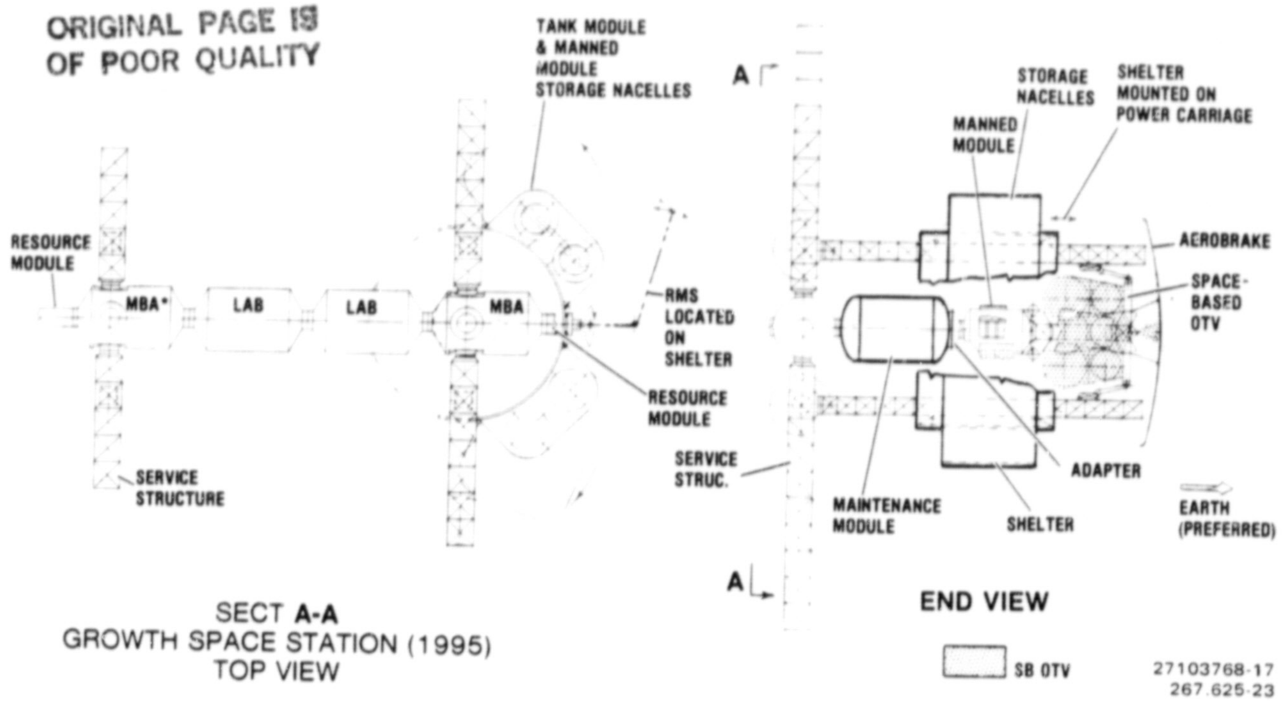

Figure 2-13. OTV Maintenance Facility - Maintenance Module with Separate Propellant Depot

2.3.3.1 Cryogenic Propellant Delivery. A variety of cryogenic propellant delivery options was examined as candidates for further study. Previous studies have indicated the high sensitivity of SBOTV costs to LEO propellant delivery costs. In a comparison with ground-based single-use upper stages such as Centaur, a space-based system will start to show a benefit only when bulk propellant delivery costs drop to about half of the standard Shuttle payload delivery cost (about $1,200/lb in 1983$). Figure 2-14 shows a comparison of payload costs per pound versus propellant delivery cost per pound. Emphasis was placed on concepts that showed promise of lowering the delivery costs to a fraction of the standard cost. Table 2-20 summarizes the relative merit of a number of propellant delivery concepts. Figure 2-15 illustrates these concepts, together with gross estimates of propellant delivered.

Chief among the concepts examined were those designed to recover residuals in the external tank (ET). At MECO the ET has achieved 98% of orbital velocity with expected minimal residuals of 9380 pounds with a full payload. With average manifesting efficiency, less than the maximum payload weight will be lofted and therefore ET residuals could be expected to rise to as much as 25,600 pounds for a nominal mission.

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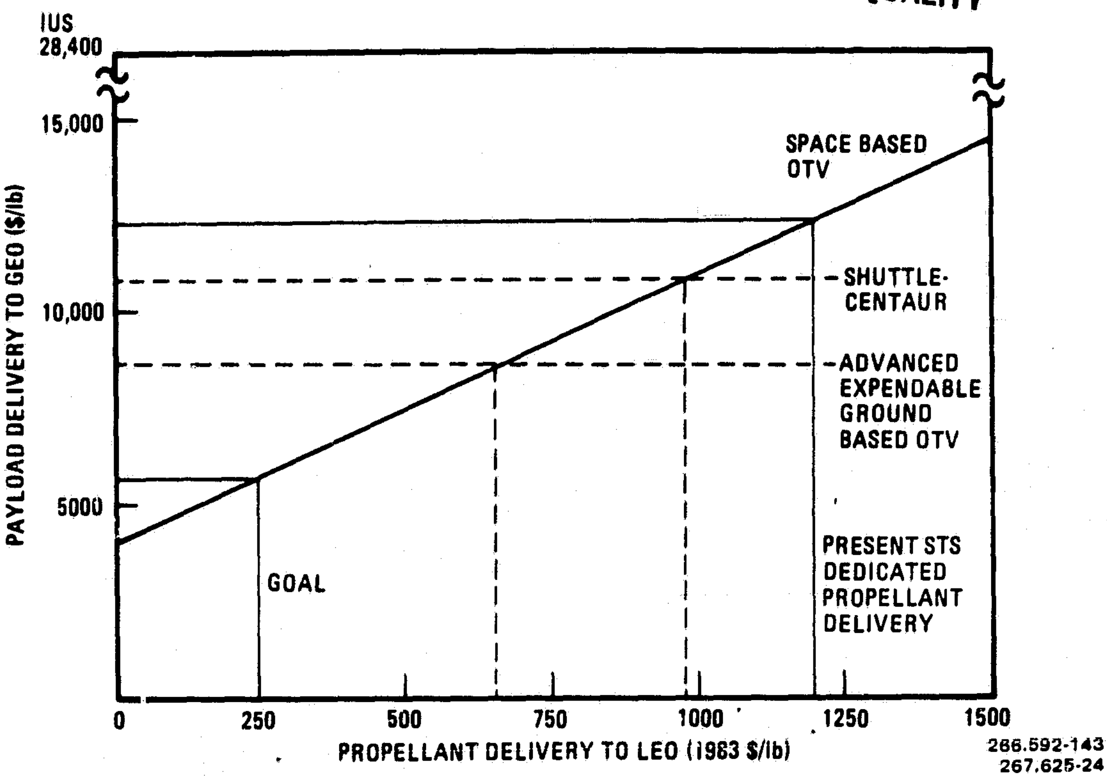

Figure 2-14. Operating Cost Comparison of GEO-Transportation Systems

Of the five ET scavenging concepts considered, the OTV Residual Recovery or "Honeybee" concept was selected for further study. Concept 4, which places residual catch tanks below the ET and possibly uses these tanks directly on an OTV, comes very close to the Honeybee and also needs further study. In question is the weight and cost penalty for propellant tanks able to withstand the severe thermal and acoustic environment at the aft end of the ET. Primary advantage of Concept 1 is simplicity of design and operation. Our analysis indicates that most STS missions will be volume limited, not weight limited, and the practical utility of any concept that restricts payload bay length is therefore questioned. Concept 2 overcomes this last deficiency at the expense of operational simplicity by placing residual catch tanks below the payload bay between the frame elements. Volume restrictions between the frames may limit the amount of residuals that might be recovered.

Other concepts, which do not rely on ET scavenging to deliver cryogens to LEO, include the obvious approach of simply placing propellant tanks in the payload bay and taking up a full load of propellant, about 58,000 pounds. A major disadvantage that precludes this concept from consideration as a primary means of propellant delivery is the high cost.

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Table 2-20. Cryogenic Propellant Delivery to LEO - Concept Evaluation

CONCEPT	RATING*								
	ORBITER PAYLOAD RESTRICTIONS		STS EQUIPMENT MODIFICATIONS REQUIRED		IMPACT ON LAUNCH** SERVICES	ORBITAL FACILITIES REQUIRED	OPERATIONAL RELIABILITY & COMPLEXITY	PROPELLANT DELIVERY COST/LB	TOTAL
	LENGTH	WEIGHT	ORBITER	ET					
ET SCAVANGING CONCEPTS									
(1) ORBITER PAYLOAD BAY TANKS	1	1	4	3	4	4	4	1	22
(2) ORBITER MIDFUSELAGE TANKS	4	2	3	3	3	3	3	3	24
(3) ORBITER WING TIP TANKS	4	1	1	2	1	3	1	2	15
(4) AFT CARGO CARRIER TANKS	4	3	4	2	3	4	3	4	27
(5) OTV RESIDUAL RECOVERY	4	4	4	2	4	4	2	4	28
OTHER ORBITER CONCEPTS									
(6) DEDICATED PAYLOAD BAY TANKS	1	1	4	3	4	4	4	1	22
(7) MIDFUSELAGE H_2O TANKS	4	3	3	4	3	1	4	3	25
HEAVY LIFT LAUNCH VEHICLES									
(8) ET TANKER	–	–	1	4	4	3	4	4	20
(9) DEDICATED SEPARATE TANKS	–	–	1	4	3	4	2	4	18

*WORST ← 1 2 3 4 → BEST

**NO. OF FLIGHTS REQUIRED AND GROUND MODIFICATIONS TO EQUIPMENT/PROCEDURES REQUIRED

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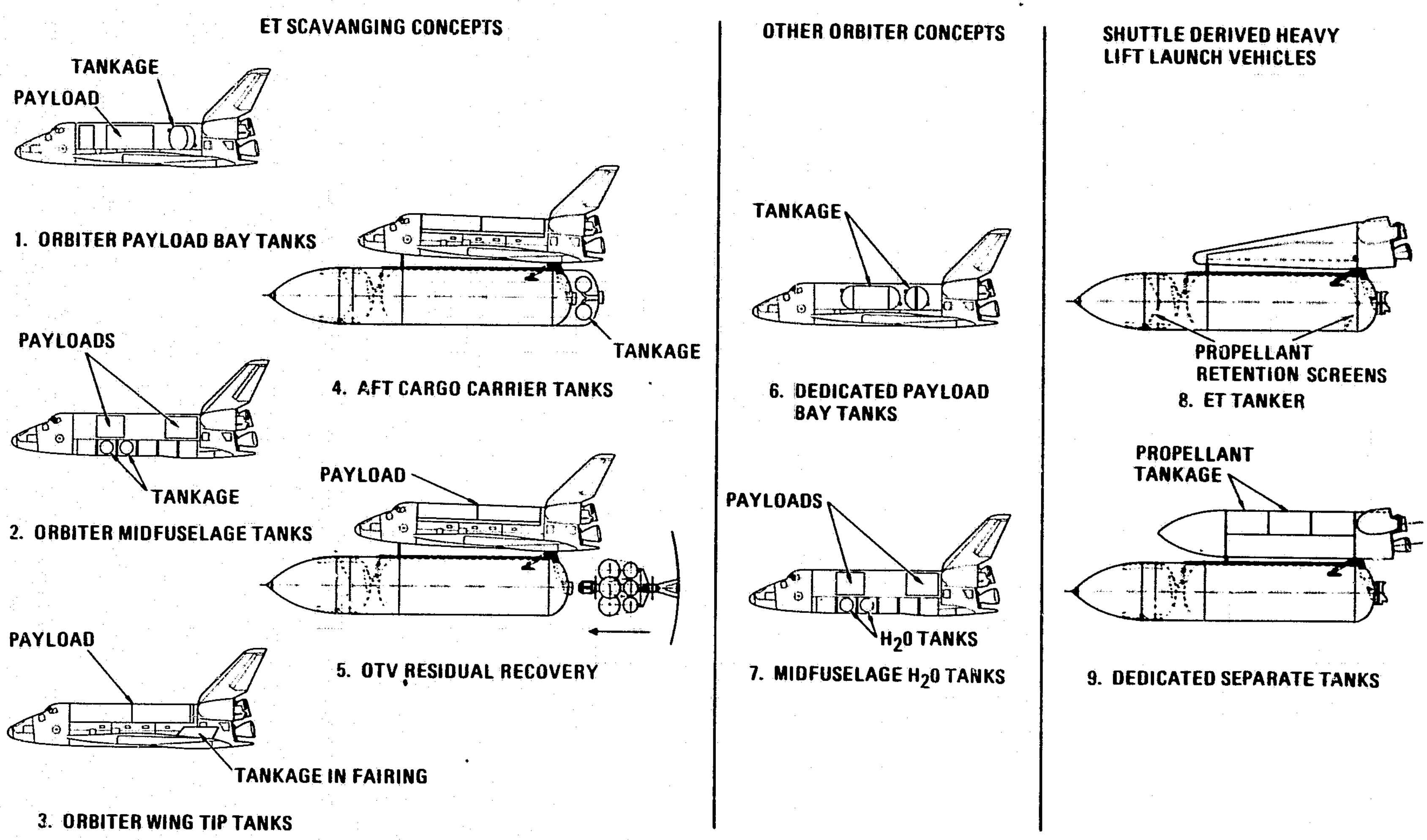

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Figure 2-15. Propellant Delivery to LEO Concepts

Another concept examined several years ago utilizes the excess payload weight available on most missions to transport 10,000-25,000 pounds of water held in tanks below the payload bay. A large solar array on the Space Station would then power an electrolysis operation to separate the water into hydrogen and oxygen, liquefy them, and store them for later use. This concept has several advantages over others in that it takes advantage of the average volume-limited payload and carries up a relatively high-density liquid. A disadvantage is in the large on-orbit facilities requirement and the excess oxygen produced (20% by weight) beyond requirements by an OTV (operating at a 6:1 mixture ratio). However, the excess could be used as a Space Station environmental consumable.

For the mature OTV traffic model, large quantities of cryogens will be required on orbit and this can only be met by a new Heavy Lift Launch Vehicle (HLLV). Shuttle derived vehicles that exchange the Shuttle Orbiter for an unmanned payload capsule hold the most promise. Concept 9 shows this payload capsule configured as propellant tanks. This concept has the advantage that these same tanks could be attached to the Space Station and used directly for propellant supply there. A disadvantage is that these tanks are too large to be returned to earth on the Shuttle and would therefore have to be thrown away, along with the ET, after use. Either of these HLLV concepts can loft about 200,000 to 220,000 pounds of propellants while the largest tanks that can be placed in the Orbiter will only hold 140,000 pounds of O_2/H_2 at a nominal 6:1 mixture ratio.

Concept 8, chosen for later study, overcomes this disadvantage by leaving the cryogens on the ET and having only an engine pod attached to it. Cryogens are then offloaded from the ET at the station and the ET disposed of as desired. Advantages include minimal change required to the ET and elimination of the need for a new set of flight qualified cryogenic tanks.

2.3.3.2 Honeybee ET Scavenging Concept. The Honeybee concept utilizes the automatic rendezvous and propellant loading/unloading capabilities of the OTV to directly off-load residuals from the ET. The OTV's light weight and high maneuverability are utilized to dock with the ET within 30 minutes of MECO. Boiloff losses, particularly with the LH_2, are therefore minimized without the added complexity and reduced manifesting efficiency inherent with payload bay or aft cargo carrier propellant tank concepts.

Thermodynamic analysis of the Honeybee concept is reviewed in 2.3.3.4. The analysis indicates that 14,200 pounds of usable LO_2/LH_2 can be extracted from the ET on a nominal mission. The OTV utilizes 2400 pounds of its own propellant to recover this, and an additional 500 pounds is lost through inflight boiloff from the OTV tanks and during transfer to the Space Station holding tanks. The net profit of propellant per mission is therefore 11,300 pounds.

Figure 2-16 illustrates the principal features of the Honeybee Concept. An OTV is launched from the Space Station 1-1/2 to 6 hours before the Shuttle launch. The OTV (without payload) would follow a transfer orbit to the rendezvous orbit (50 to 100 n.mi.) and rendezvous with the Orbiter/ET. Any Shuttle flight going to the Space Station and quite a few others going to nearby inclinations would be economically accessible by the OTV. Once the OTV is in the rendezvous orbit, the Shuttle ascent trajectory software is updated with the exact orbit parameters. The OTV remains for up to three orbits before STS launch.

After launch, as the STS nears MECO, the OTV tracks the rising stack and begins to compute intercept maneuvers required.

To reduce propellant boiloff, it is desirable to reduce liquid-vapor mixing, which is exacerbated by springback of the aft bulkhead of the ET. Several procedures before and after MECO may prove feasible to reduce liquid-vapor mixing. These include:

a. Deep throttling of the Space Shuttle Main Engines (SSMEs) to 50%.

b. Sequential shutdown of the SSMEs.

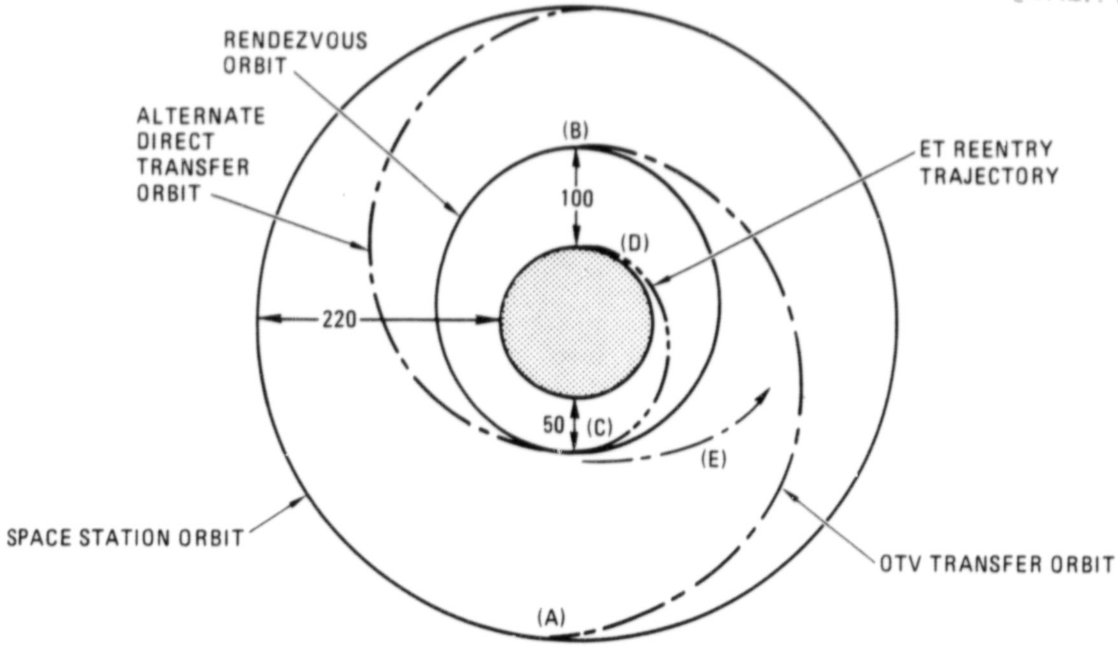
c. Intermittent firing of one or two aft facing PRCS engines after MECO until OTV terminal maneuvers.

d. Addition of aft-directed propulsive vents to the ET.

The ET is shown modified with a docking port on the aft end. The docking port has propellant, electrical, and command/data line disconnects, and structural attachments to interface with the OTV. A blow-off cover protects the docking port during ascent. Propellant lines lead directly into the ET H_2 tank and to the ET side of the O_2 interface with the Orbiter.

Due to the large amount of O_2 in the Orbiter at MECO, it may be economical to also tap the orbiter side of the disconnect. Electrical and command/data lines connect with the ET wiring harness and thence into the Orbiter through the existing Orbiter disconnect panel.

The Orbiter remains attached to the ET while the OTV, under automatic control, maneuvers to intercept. Under normal operation the OTV would use its automatic rendezvous/docking sensors and guidance and navigation (G&N) computer to perform the docking. During terminal docking maneuvers, the Orbiter would have override capability to cancel the docking and separate the OTV from the ET/Orbiter. The existing TV camera in the aft ET attachment well of the Orbiter is modified for tilt and pan to allow the Orbiter crew to monitor the docking operation. In addition, the OTV would have a TV camera to allow crew monitoring of the docking operation. If a hard dock cannot be achieved between the OTV and the ET, the Orbiter can inject the ET into a controlled reentry.



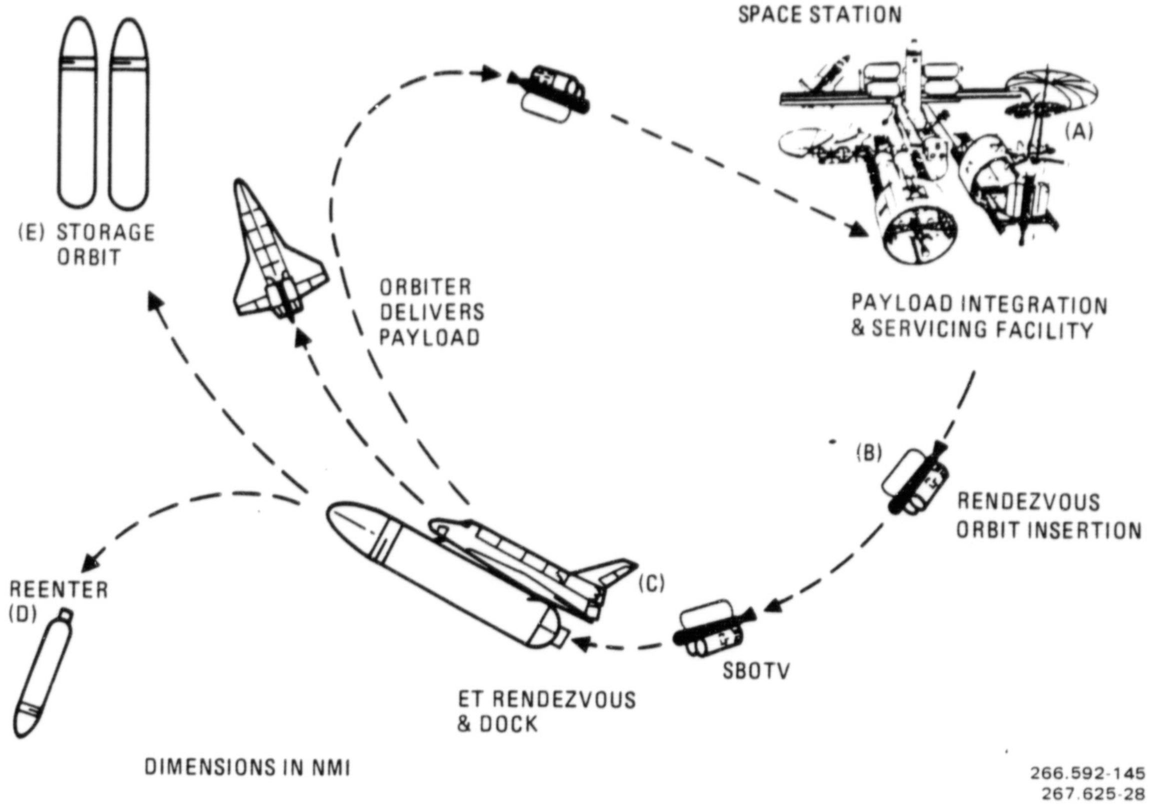


Figure 2-16. Honeybee ET Scavenging Concept Orbit Mechanics

The Orbiter disconnects from the ET once verification of an OTV hard dock is received and separates in the standard procedure with PRCS firings. Once safe separation has been achieved the Orbiter crew may elect to remain nearby to monitor the propellant loading operation or may use the OMS engines to proceed to their assigned mission orbit.

The OTV loads the ET residuals with a combination of pressure head caused by firing its main engine and pump head provided by cryogenic pumps on board the OTV. First the OTV aligns itself along the vehicle velocity vector such that the main engine serves to decelerate the ET. The main engine is cycled up to 20% thrust and decelerates the ET for 4-5 minutes, imparting a ΔV of 150-200 ft/sec. ET residuals are settled, collected, and pumped into the OTV tanks during this operation. Once all accessible residuals are loaded, the propellant lines are disconnected, the OTV separates, and the ET is programmed to tumble in preparation for reentry. The OTV then accelerates into a return transfer orbit to the station.

Preliminary performance analysis indicates a minimum ΔV requirement for the entire OTV operation of 1390 ft/sec (from Space Station undock to redock), which consumes 1770 pounds of OTV propellant. With orbit phasing and other intermediate orbit maneuvers to intercept the Shuttle, the nominal ΔV for this operation would rise to approximately 1800 ft/sec, requiring 2400 pounds of OTV propellant. In addition to this propellant requirement, there are also the orbiter RCS propellant requirements, which have not been assessed here.

2.3.3.3 ET Tanker Concept. Large quantities of propellant may be delivered to LEO at low cost with little disruption of other high priority STS traffic with a Shuttle derived Heavy Lift Launch Vehicle (HLLV). The ET tanker concept avoids the added cost and weight penalties of separate "payload" propellant tanks for the HLLV. For such large propellant quantities, boiloff from the existing ET is a minor concern for the 24-hour (maximum) period from MECO to propellant offload into Space Station dewars. The ET tanker is also compatible with other applications for an HLLV; a cylindrical payload container/fairing may be substituted for the aerodynamic fairing illustrated in Figure 2-17. Maximum commonality with Shuttle components assures relatively low development cost. The potential for disassembly of high value subsystems, such as the SSME avionics, and others, should reduce operational costs substantially as well.

Preliminary performance analysis of a representative ET tanker indicates that 210,000 - 220,000 pounds of usable propellant is available at MECO on a direct ascent to the Space Station. To be conservative, a figure of 210,000 pounds is utilized in the thermodynamic analysis, which follows in Section 2.3.3.4.

The representative ET tanker is illustrated in Figure 2-17. The ET is modified in only two major respects:

a. A berthing system is incorporated into the aft end of the tank for structural attachment to the Space Station. The data and control harness for the ET/propulsion module also passes through the berthing system interface. An insulated blowoff cover, which can be removed manually in the event of failure, protects the berthing system during ascent.

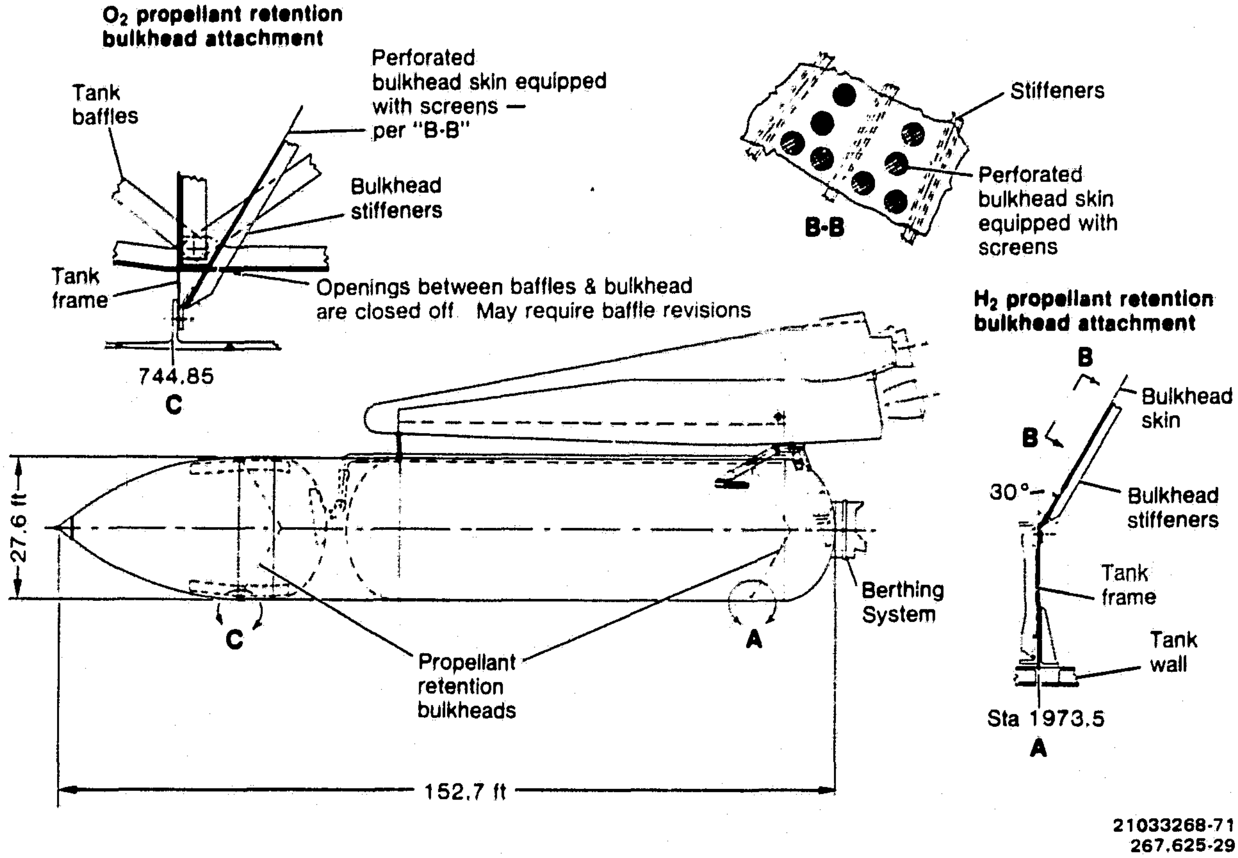


Figure 2-17. ET Tanker Concept

b. Conical stiffened bulkheads with multiple capillary screens are added to the O_2 and H_2 tanks, supported from existing ring frames. These bulkheads prevent propellant drift to the forward portions of the tanks, thus maintaining propellant vapor stratification. Maintaining vapor stratification significantly reduces boiloff rates and venting requirements. The bulkheads are made up of stiffened stainless sheet material perforated with 3 to 8 inch diameter holes to which are attached capillary screens. Screen area to total area ratio is about 1:2; therefore, propellant feed during ascent is not affected.

Several different concepts for the propulsion module are feasible. A chief distinction is whether the propulsion module is recovered ballistically or by on-orbit disassembly and Shuttle return of key subassemblies. For high mission modes, ballistic recovery tends to show a benefit due to shorter turnaround time, minimized spares requirements and the fact that the entire propulsion module is basically reusable. For lower mission models, the additional costs associated with design of the ballistic recovery propulsion module, and the reduced payload deliverable to orbit as a result of the higher

weight of the recoverable structure, push the trade toward the on-orbit disassembly option. Propellant delivery requirements only dictate two to four ET tanker flights per year and other uses for the HLLV only bring the total number of missions to 10 or less by the turn of the century. Therefore, disassembly at the Space Station is the assumed recovery technique.

Basically, the propulsion module is the aft section of the existing Orbiter without the current thermal protection system (TPS) and with certain design provisions to aid zero-g disassembly of components. Additional vernier RCS engines, both forward and aft, aid in Station docking maneuvers. FRSI, LRSI and HRSI insulation is replaced with spray-on foam insulation (SOFI) (similar to that used on the ET) for the side areas while a spray-on ablative foam is used to insulate the aft bulkhead from radiant heat generated by the SSMEs.

A new keel structure attaches to the propulsion module and carries axial loads to the existing ET attach. This minimizes redesign for the ET, which otherwise would have to be stiffened to take the axial loads imparted by the SSMEs. For payload application, this keel structure would carry payload attach frames and a new payload shroud. Payloads up to 90 feet long and 20 feet in diameter could be accommodated.

In operation the ET tanker follows a direct ascent trajectory to the Space Station at about 220 n.mi. OMS engines or the existing PRCS engines are used for terminal phasing maneuvers. The propulsion module remains attached to the ET until final disassembly and disposition at the Space Station. The ET tanker docks with the station under manual control from the station using the propulsion module PRCS and VRCS engines.

Once docked, the propellant transfer arms (see Figure 2-18) are swung down and engaged with the existing Shuttle overboard dumps. Propellant transfer is aided by performing Space Station orbit-maintenance burns concurrently. Acceleration levels of 0.0005-0.00010g required for quarterly orbit-maintenance burns aid in propellant acquisition and transfer to Station tanks. Propellant transfer is performed through the existing O_2 and H_2 feed systems on the ET and requires between 5 and 20 minutes. The ET and propellant lines are then vented for several hours.

After propellant transfer and venting the disassembly operation commences. Space Station RMSs, augmented with versatile service attachments, assist EVA crewmen in operations. Key components that could be disassembled and packaged for Shuttle return include:

a. SSMEs

b. OMS/RCS Aft Pods

c. RCS Forward Pod

d. Engine Controllers

e. Main Avionics Suite

f. APUs

g. Miscellaneous Propellant Pumps, Valve Assemblies, etc.

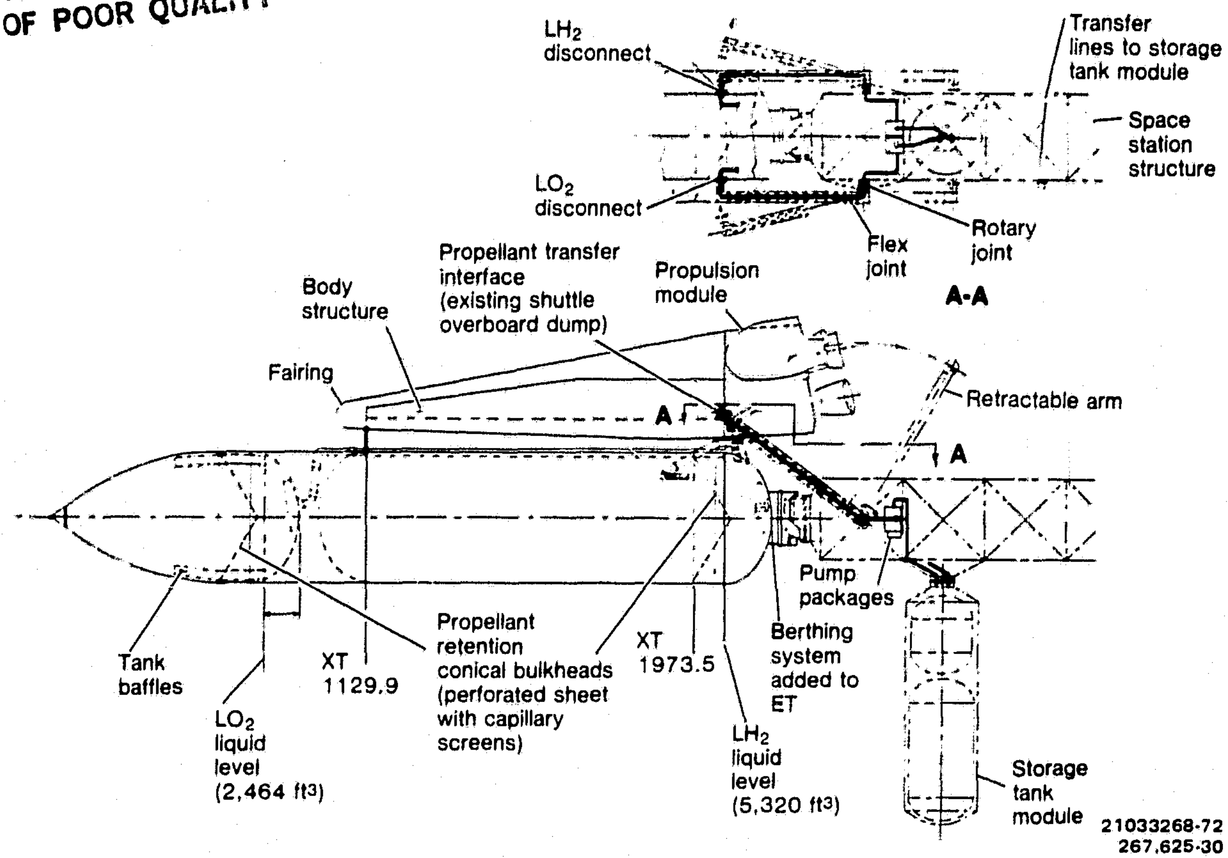


Figure 2-18. ET Tanker Propellant Transfer Concept

Preliminary packaging indicates that these components could be returned on two or three Orbiter flights. The ET and remaining structure/hardware could be deorbited by the TMS or placed in a higher storage orbit for later use. ETs could be attached together with the Space Station and Orbiter attachments to reduce drag losses in long term storage.

2.3.3.4 Thermodynamic Analysis of Cryogenic Propellant Delivery Systems

Residual Analysis, Honeybee Scavenging Concept. A preliminary analysis was performed on the ET to assess possible propellant scavenging concepts with an OTV. The basic scenario that is proposed for propellant scavenging by an OTV is outlined in Section 2.3.3.2.

The propellant residuals available at MECo are given in Table 2-21 for both the LH_2 tank and LO_2 tank, for an 85% loaded Orbiter at launch and a nominally loaded ET. Table 2-21 is taken from recently updated JSC data on residuals expected on the external tank at MECO.

Table 2-21. Liquid Residual Available at MECO for Propellant Scavenging, Honeybee Concept

	LO_2 (lbm)	LH_2 (lbm)	LO_2/LH_2 (lbm)
Orbiter	4,629	307	4,936
External tank	2,001	2,695	4,696
+ 15% reduced payload	(10,365)	(0)	(10,365)
Total external tank	12,366	2,695	15,061

The assumptions that were made in a thermal analysis of the ET to determine the residuals available after MECO are:

a. The propellants remain settled near the aft bulkhead of the ET up to MECO, after MECO before the OTV docking, during the docking, and during the propellant transfer operation.

b. The worst case thermal condition prevails during docking, i.e., solar heating of the aft bulkhead of the ET LH_2 tank (25 Btu/sec) and Orbiter heating of the LO_2 feedline (15 Btu/sec).

c. The propellants are in a saturated liquid state at 34 psia for LH_2 and 22 psia for LO_2. This is a conservative assumption for liquid residuals for it will give a maximum liquid boiloff for given heating rates.

d. A representative time of 30 minutes for the docking operation of the OTV with the ET. This time will be from MECO to separation of the OTV/ET combination from the orbiter.

Using the above assumptions, it is possible to calculate residuals available after MECO. These are presented in Figure 2-19. The LH_2 and LO_2 liquid residuals are shown against time from MECO. The oxidizer-fuel ratio is also shown so that an understanding can be had of oxygen-to-fuel (O/F) ratios that would be transferred to the OTV. One item to note is the rapid change in the O/F ratio due to the higher boiloff rate of LH_2. The initial low O/F ratio of 4.5:1 is due to the fuel bias (1001 lbm) at liftoff, done to ensure no oxygen-rich shutdown of the engines.

The actual transferred liquid quantities are presented in Table 2-22 for four different transfer times. These quantities reflect the residuals remaining in the external tank due to vapor pull-through during transfer.

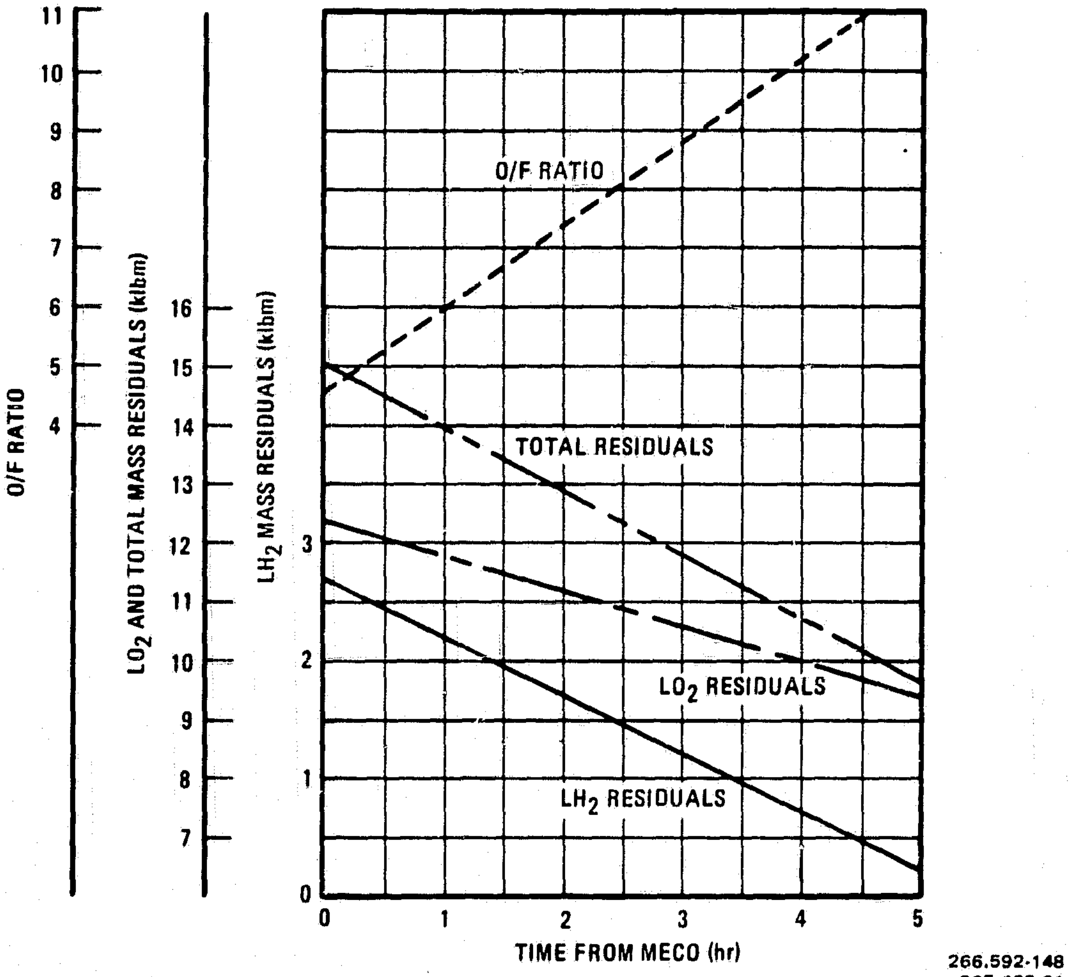


Figure 2-19. Residual Masses and O/F Ratio, Honeybee Concept

Table 2-22. Actual Transferred Liquid Propellants, Honeybee Concept

Transfer Time (minutes)	6	30	45	60
Transfer rate, (gpm) LH_2	625.7	125.14	83.43	62.57
LO_2	221.64	44.33	29.55	22.16
LH_2 (lbm)	1,895	2,073	2,096	211
LO_2 (lbm)	11,589	11,608	11,611	11,612
O/F ratio of transfer mass	6.1	5.6	5.5	5.5
Total transfer mass (lbm)	13,484	13,681	13,707	13,7234

The actual transfer of liquids from the external tank to the OTV involves several technical issues that must be resolved before a thorough concept assessment is made. Some of these issues are:

a. The Orbiter/ET thermal environment

b. The routing and connection methods of the transfer line.

c. The pressurization fluid and quantity needed to achieve transfer.

d. Fluid pumping configuration sizing (i.e., type and power needed for transfer pump).

Basically the transfer system needs a better definition so that a meaningful trade study can be performed to assess the Honeybee propellant scavenging concept and what is required (pressurization fluid, electrical power, external tank modifications, and OTV modifications) to acquire the approximately 5000 gallons of propellants from the external tank at MECO. The concept of propellant scavenging from the external tank appears to be technically feasible from this analysis.

Residual Analysis - ET Dedicated Tanker Concept. The use of the ET as a dedicated tanker has received a preliminary analysis to determine the residuals available for the holding dewars of a Space Station. The assumptions made in the Honeybee concept for the thermal environment and the propellant initial conditions are again used for the dedicated tanker concept to give a "worst case" approach to propellant quantities.

The initial liquid residuals available for propellant transfer are derived from the case of direct ascent of the ET to the Space Station with OMS and/or PRCS firings for orbit phasing. The propellant residuals expected are given in Table 2-23.

Using the assumption of the Honeybee concept for the thermal environment, an estimate of the propellant residuals after MECO can be seen in Figure 2-20. Note that the effect of fuel bias at launch is minimal for such large propellant quantities at MECO so that the O/F ratio degrades from a 6:1 ratio.

Table 2-23. Dedicated ET Tanker Concept, Initial Propellant Masses at Transfer Vehicle MECO

Total residual propellants (lbm)	210,000
O/F ratio	6:1
Initial LH_2 mass (lbm)	28,571
Initial LO_2 mass (lbm)	171,429

The liquid quantities transferred to the Space Station dewars assume:

a. Propellant transfer starts 4 hours after MECO.

b. The Space Station transfer lines are at space temperature of approximately 77K.

c. The propellant is retained between the propellant retention bulkheads and aft bulkheads of both LH_2 and LO_2 tanks.

d. The transfer vehicle/ET/Space Station is given an acceleration of 0.0007g for 4.2 minutes to settle the propellants before liquid transfer occurs.

Using these assumptions, the liquid quantities that can be transferred from the external tank have been calculated and are given in Table 2-24. These quantities are representative of amounts of liquid propellants available less the vapor pull-through volumes in the tanks and feedlines.

Table 2-24. Actual Transferred Liquid Propellants, Dedicated ET Tanker Concept

Transfer Time (minutes)	6	30	45	60
Transfer rate, (gpm) LH_2	6,633	1,327	884	663
LO_2	3,073	615	410	307
LH_2 (lbm)	18,734	25,162	25,834	26,159
LO_2 (lbm)	176,753	177,097	177,144	177,171
O/F ratio of transfer mass	9.43	7.04	6.86	6.77
Total transfer mass (lbm)	195,487	202,259	202,978	203,330

One modification to the transfer technique that would give lower transfer times and low ET residuals would be the use of a variable speed transfer pump, so that as the quantities of liquid approach the pull-through heights, the pumping speed is lowered to a lesser quantity to reduce residual masses.

Some of the technical issues that face the assessment of the dedicated ET tanker concept are:

a. The thermal environment of the transfer vehicle/ET combination during operation.

b. Complete system sizing of the transfer lines, pressurization lines, and power level requirements of the Space Station transfer schematic.

c. Design of Space Station tanking dewars.

d. Modifications necessary to ET for tanker concept.

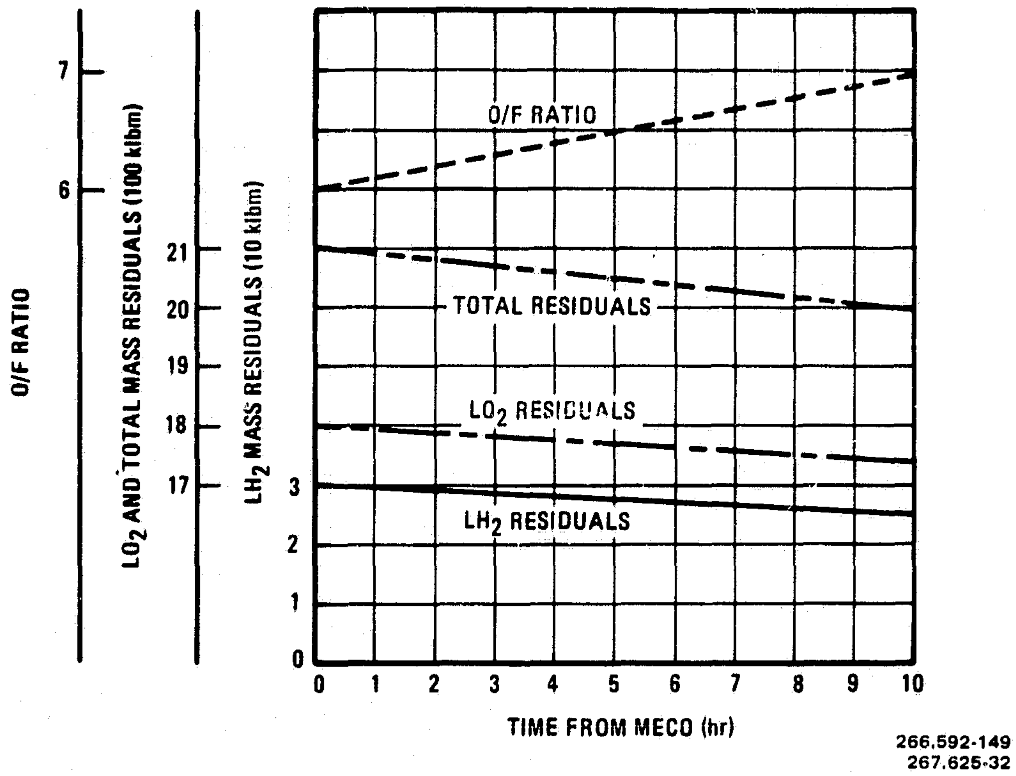


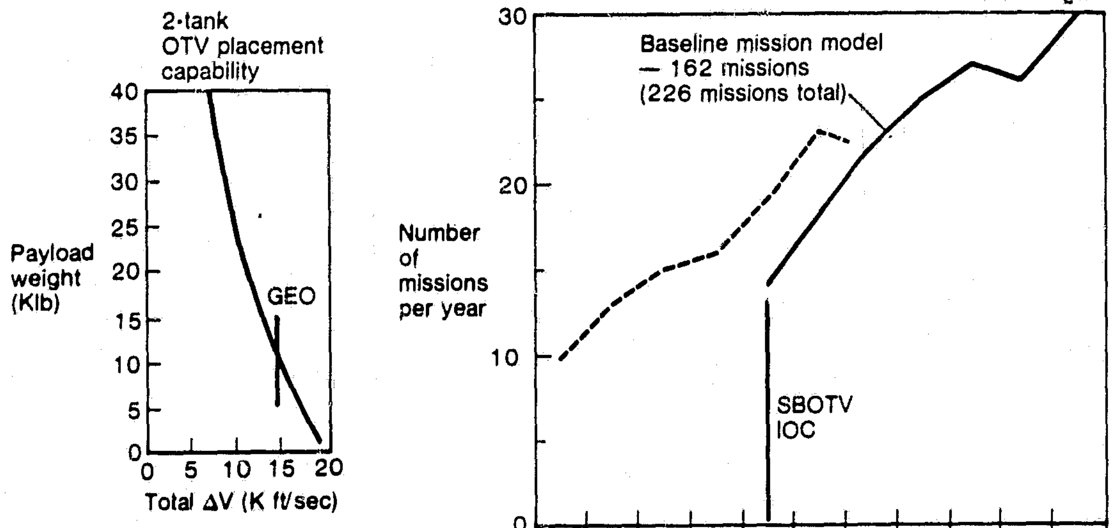
Figure 2-20. Residual Masses and O/F Ratio Dedicated ET Tanker Concept

Addressing these technical issues facilitates a better understanding of the Space Station tanking concept and optimization of the transfer technique and determination of the most economical method for propellant delivery can thus be realized.

2.3.3.5 OTV Mission Model Propellant Requirements. Figure 2-21 depicts propellant requirements per year assuming the entire OTV mission model. These figures therefore represent a maximum propellant requirement. Given a nominal 60-80% payload capture ratio (the remainder of the missions going to Ariane, Atlas Centaur II, etc.) the propellant requirements will be reduced correspondingly.

The solid line on the chart represents actual OTV requirements assuming a 1994 IOC and a 2-year phase-in period before all traffic demand is met. The phantom line to the left is only for reference, indicating the entire trend of the propellant requirements through the decade.

Given an STS traffic model calling for 40 STS missions total from both KSC and VAFB, it seems likely from an extrapolation of the current mission manifest that about 24 missions per year would be accessible from the 28.5-degree Space Station for Honeybee scavenging. This yields a net propellant delivery of just under 280 klb per year. This is less than the first year requirements for the all-up mission model and even for the reduced mission requirements of Rev 6.



Mission type	90	91	92	93	94	95	96	97	98	99	2000
Placement	(10)	(13)	(10)	(14)	13(5)	15(5)	18	19	25	23	26
Retrieval	–	–	–	–	–	1	2	–	1	1	–
Service in-situ	–	–	(1)	–	–	1	1	2	1	1	3
Escape	–	–	(4)	(2)	(1)	(1)	–	4	–	–	–
Manned sortie	–	–	–	–	–	–	–	–	–	1	1

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Figure 2-21. OTV Propellant Requirements for 28.5-degree Operations

Therefore, a supplementary means of delivering OTV propellants would be required sometime within the first 2 years of operation. Carriage of propellant in dedicated payload bay tankage to the Space Station is a logical possibility. However, by 1997 this would require an additional seven Shuttle missions just for propellant delivery.

The ET tanker offers a more plausible means of propellant delivery that is capable of meeting the entire requirement without the added complexity of scavenging concepts and with minimal impact on the STS launch schedule. Only two to three tankers a year will meet the entire requirement and not impose a great burden on the KSC launch facilities.

2.3.4 CREW MODULE. For manned missions the operational functions that were derived for the module, for the purpose of identifying technologies that need to be developed, are listed in Table 2-25. The operation is based on the "maintenance module" facility configuration shown in Figure 2-9. This configuration was used to develop the operations because it shows direct access to the crew module and provisions for storing the module. The "maintenance module" is not essential to the operation, but the berthing arrangement is important. It allows shirt-sleeve ingress/egress between Space Station and crew module for a more efficient crew transfer and internal maintenance activities. The maintenance operations are accomplished on the crew module elements listed in Table 2-26. These element descriptions were taken from Reference 3. The Manned Geosynchronous Mission Requirements and

Table 2-25. Crew Module Operational Functions at the Space Station

BERTH OTV

- RENDEZVOUS OTV/CM NEAR STATION
- RENDEZVOUS AND DOCK OMV WITH OTV/MM
- MANEUVER OTV/CM TO STATION WITH OMV
- CAPTURE OTV/CM AT STATION WITH RMS
- BERTH OTV/CM IN MAINTENANCE DOCK WITH RMS
- ROTATE AND MOVE OTV/CM TO ENGAGE STATION AIR LOCK
- EXTEND SHELTER TO COVER OTV

TRANSFER CREW TO STATION

- EQUALIZE CREW MODULE TO STATION PRESSURE
- OPEN MANNED MODULE AND STATION ACCESS DOORS
- TRANSFER CREW FROM MANNED MODULE TO STATION

DISENGAGE OTV FROM MODULE

- UNLATCH OTV MODULE INTERFACE
- DISENGAGE OTV FROM MODULE

REMOVE WASTE MATERIALS FROM MODULE

- DETACH WASTE MANAGEMENT SYSTEM FROM MODULE
- MOVE WASTE SYSTEM TO EARTH RETURNABLE LOGISTICS MODULE

INSPECT MODULE

- PERFORM VISUAL INSPECTION
  - TV INSPECTION (MODULE EXTERNAL)
  - IVA DIRECT INSPECTION (MODULE INTERNAL)
- DETERMINE MODULE STATUS
- WHEN FAULT OR DAMAGE IS DETECTED
  - PERFORM DAMAGE ASSESSMENT (TV/EVA)
  - FAULT ISOLATE TO REPLACEABLE UNIT
- FORMULATE INTEGRATED MAINTENANCE PLAN

PERFORM MODULE MAINTENANCE

- PERFORM SCHEDULED/UNSCHEDULED MAINTENANCE TASKS
- PERFORM SYSTEM OPERATIONAL TESTING
- PLACE MODULE IN STORAGE (IF NOT REQUIRED AT THIS TIME)

STORE MODULE

- DEACTIVATE AND SECURE ALL MODULE SYSTEMS
- GRASP MODULE WITH STATION RMS
- DISENGAGE MODULE FROM STATION AIR LOCK
- TRANSLATE MODULE TO STORAGE AREA AND SECURE
- RELEASE AND STOW RMS

ACTIVATE MODULE FROM STORAGE

- ASSURE STATION AIR LOCK IS CLEAR
- GRASP MODULE WITH STATION RMS
- RELEASE MODULE FROM STORAGE AREA
- TRANSLATE MODULE TO STATION AIR LOCK
- ENGAGE AND LATCH MODULE TO STATION AIR LOCK
- ACTIVATE MODULE SYSTEMS
- EQUALIZE MODULE TO STATION PRESSURE
- OPEN MODULE AND STATION ACCESS DOORS
- RELEASE AND STOW STATION RMS
- PERFORM MODULE FLIGHT VERIFICATION CHECKS

REPLENISH CREW EXPENDABLES

MATE OTV TO MODULE

- MOVE OTV TO MODULE
- ENGAGE AND LATCH OTV/CM INTERFACE
- PERFORM OTV TO MODULE INTEGRATION TEST

TRANSFER PROPELLANT FROM STATION TO OTV

- VERIFY STATION TO OTV INTERFACE INTEGRITY
- PERFORM PROPELLANTS LEAK CHECKS
- TRANSFER PROPELLANT FROM STATION TO OTV

LAUNCH OTV/CM

- TRANSFER CREW TO MODULE
- PERFORM PRE-LAUNCH CHECKS
- DISENGAGE OTV/CM FROM STATION AIR LOCK
- RETRACT SHELTER
- ROTATE OTV/CM TO DEPLOYMENT POSITION
- GRASP OTV/CM WITH STATION RMS
- MATE OMV TO OTV/CM
- DEPLOY OTV/CM/OMV WITH RMS AND RELEASE
- MANEUVER OTV/CM TO LAUNCH POSITION WITH OMV

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Table 2-26. Basic Crew Module Elements

STRUCTURE

CREW EXPENDABLES
- WASTE MANAGEMENT & PERSONAL HYGIENE
- CLOTHING
- FOOD
- LiOH
- OXYGEN & EMERGENCY OXYGEN
- EVA & CABIN SUIT EXPENDABLES
- NITROGEN

ELECTRICAL POWER
- SOLAR ARRAYS
- BATTERIES
- FUEL CELLS
- DISTRIBUTION AND CONTROLS

AVIONICS
- CONTROLS AND DISPLAYS
- NAVIGATION AND GUIDANCE
- RENDEZVOUS RADAR
- COMMUNICATIONS, COMMAND AND CONTROLS
- DATA MANAGEMENT
- TV SYSTEM

THERMAL
- INSULATION
- RADIATORS
- CONTROLS

ECLSS
- STORAGE TANKS
- PUMPS
- FILTERS

SPACE STATION INTERFACE
- BERTHING RING
- CREW ACCESS

MISSION EQUIPMENT
- MANIPULATORS
- GRAPPLER, TOOLS

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Systems analysis Study conducted by Grumman aerospace for Nasa/JSC. (Discussion was held with Grumman personnel involved in this study.) No apparent new technology development requirements were identified. The module internal elements for life support and crew accommodations are also required on the Space Station. The external elements can be maintained in a manner similar to the OTV, using the same techniques and equipment. However, a LEO demonstration mission using the OMV to maneuver the crew module is recommended before commitment to a manned GEO mission on the OTV.

2.3.5 SPACE STATION ACCOMMODATION CONCEPTS. Table 2-27 lists the Space Station architecture provided by NASA to use in the study. It identifies the initial Station and growth Station elements. We have used these guidelines in integrating the OTV servicing facilities with the growth Station and determining the required scar provisions on the initial Station to accommodate the OTV TDMs and the growth to the full operational servicing capability.

2.3.5.1 Initial Space Station. Figure 2-22 shows a layout of the initial Station with the servicing structure attached to the MBA supporting the facilities for OMV and satellite servicing. It also shows an additional servicing structure attached to the MBA supporting the proposed OTV TDMs generated in Phase I of this study. In addition to the OTV TDMs, it shows a Shuttle/Centaur attached to the servicing structure by means of a Centaur integrated support system that is used in the Shuttle. Phase II of the study is going to analyze this approach using the Shuttle/Centaur for development of space-based OTV capabilities in Task 2.

Table 2-27. Space Station Program Architecture

1991 IOC	1995 Growth
• Core modules - 1 resource, 1 MBA, 1 HAB, 2 lab, 1 log	• Core modules - 2 resources, 2 MBA, 2 HAB, 3 lab, 1 log
• 6-8 crewmen	• 8-12 crewmen
• 60 kW user power (75 kW to bus)	• 120 kW user power (150 KW to bus)
• 300 megabit per second downlink	• 300 megabit per second downlink
• 120 cubic ft of laboratory volume	• 180 cubic ft of laboratory volume
• 2 space platforms (28.5 deg & 90 deg)	• 2 space platforms (28.5 deg & 90 deg incl)
• TMS, satellite servicing	• TMS, OTV, satellite servicing
• Station-based TMS ("smart" front end)	• Station-based TMS & OTV
• Ground support	• Ground support
• $7.5B to $9.0B cost	

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The objective of this layout is to show the size of the maintenance facilities development missions equipment in relationship with the rest of the station and what scars are need to accommodate evolution to the growth Station.

An observation that is important to the Space Station architecture is that the servicing facilities and TDM facilities for OTV/OMV/satellites are of equal magnitude with the rest of the station and are a major design driver.

2.3.5.2 Growth Space Station. Figure 2-23 shows a layout of the growth Station with two OTV maintenance facilities attached to it. We have used the maintenance module concept, described earlier in the report, to illustrate a candidate installation. This arrangement is meant to show the relative size of the required OTV maintenance facilities in relationship to the rest of the station elements and how they might be integrated into the station to keep the cg travel to a minimum.

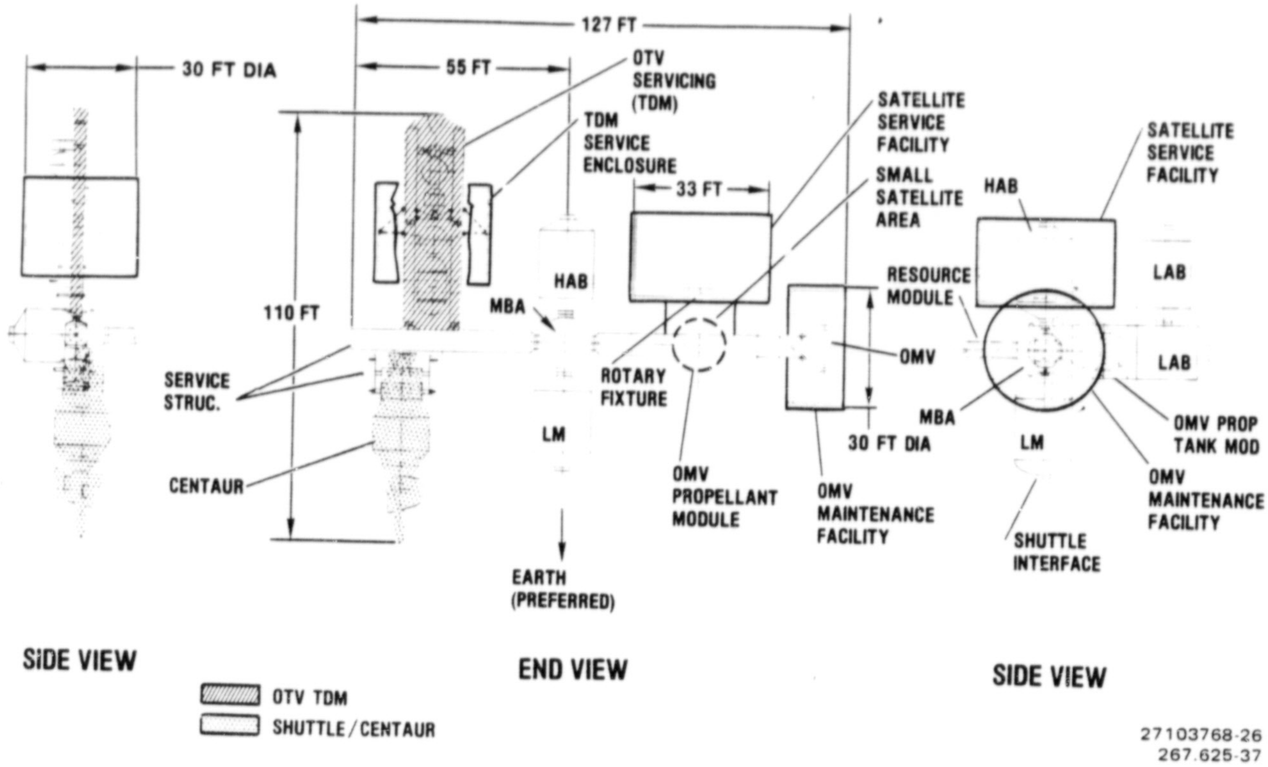

Figure 2-22. Initial Space Station with OTV TDM, Satellite and OMV Servicing, and Shuttle/Centaur

One facility is attached to the service structure required on the initial Station. The OMV/satellite servicing facilities are still required on this structure. The OTV TDM and Centaur integrated support structure will not be needed on the growth Station. They will be dismantled after their missions have been performed. Some of the OTV TDM equipment such as the servicing beams and shelter components could be used to build up the operational maintenance facility. This area on the service structure could be used for other activities after the operational facility is completed.

The second OTV maintenance facility is assembled off a service structure attached to the second MBA in the same manner as the first facility. This service structure would be available for other activities except for the ET tanker docking port on one end (as shown in previous charts).

An observation that is important to the Space Station architecture is that the servicing facilities for OTV/OMV/satellite servicing are of equal magnitude to the rest of the station and are a major design driver for the station concept.

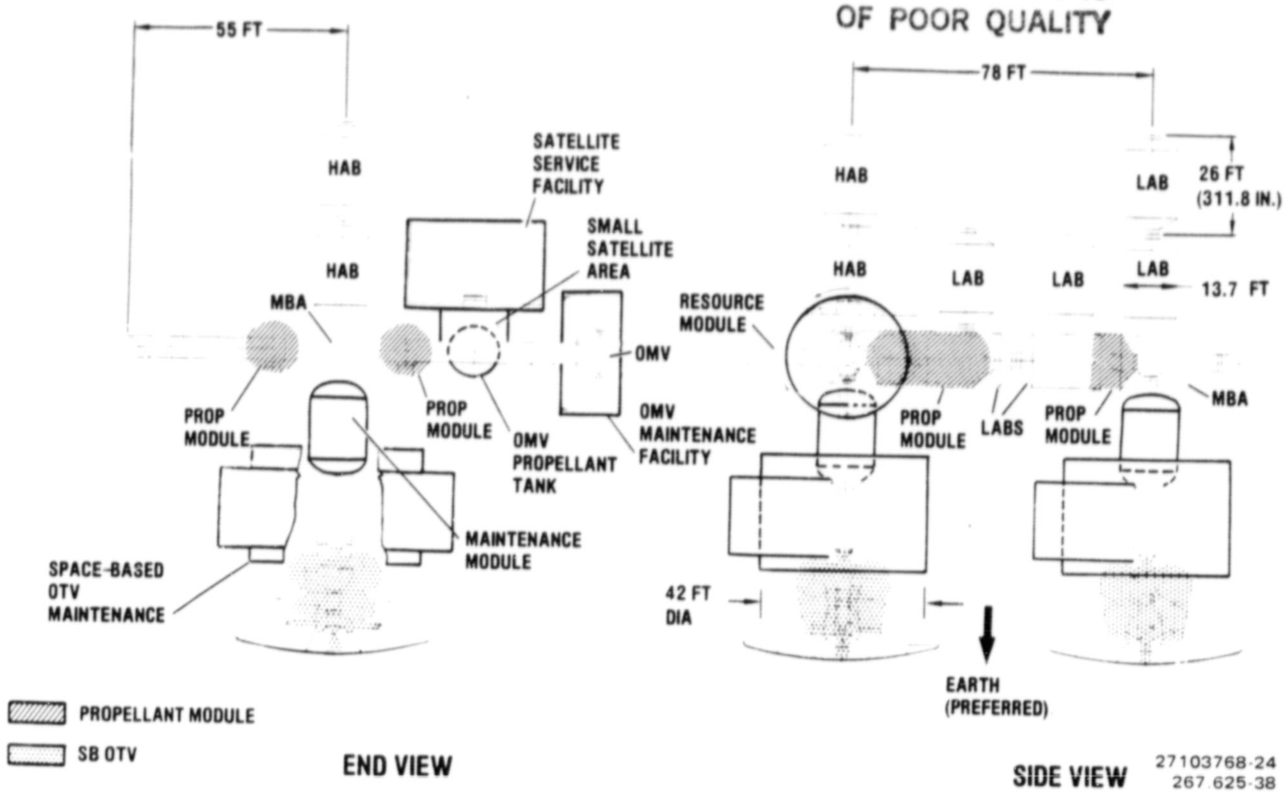

Figure 2-23. Growth Space Station with OTV Maintenance Module

Figure 2-24 shows a layout of an alternative initial Station with a single servicing structure attached to the MBA supporting the facilities for OMV, satellite servicing, and the proposed OTV TDMs generated in Phase I of this study. In addition to the OTV TDMs, it shows a Shuttle/Centaur attached to the servicing structure by means of a Centaur integrated support system that is used in the Shuttle. This phase of the study is going to analyze using the Shuttle/Centaur for development of space-based OTV capabilities in Task 2. This arrangement is directed at using the servicing facilities to provide gravity gradient stabilization for the station.

The objective of this layout is to show the size of the maintenance facilities and development missions equipment in relationship with the rest of the station and what scars are needed to accommodate evolution to the growth Station.

As was the case with the previous concept, the servicing facilities and TDM facilities for OTV/OMV/satellites are of equal magnitude with the rest of the station and are a major design driver.

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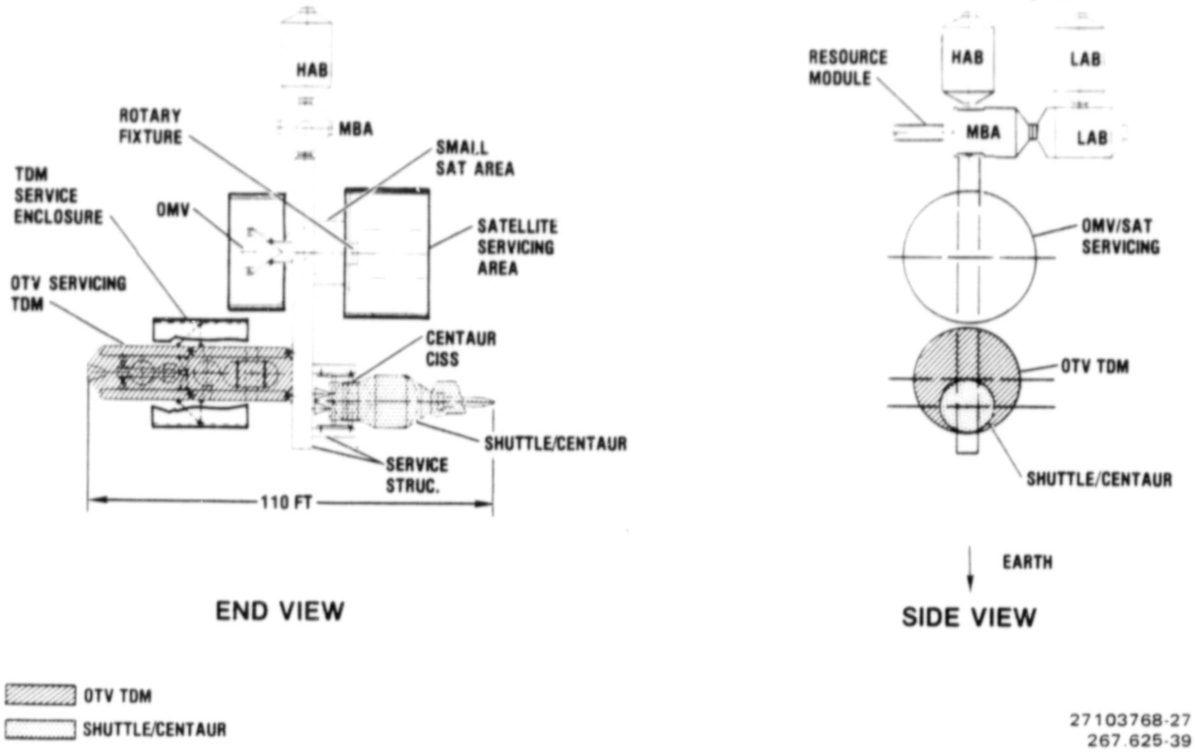

Figure 2-24. Initial Station (Alternative) - Satellite/OMV Servicing Plus OTV TDM/Shuttle Centaur

Figure 2-25 shows a layout of an alternative growth Station with two OTV maintenance facilities attached to it. We have used the maintenance module concept, described earlier, to illustrate a candidate installation. This arrangement is meant to show the relative size of the required OTV maintenance facilities in relationship to the rest of the station elements and how they might be integrated into the station. This arrangement is directed at using the servicing facilities to provide gravity gradient stabilization for the station.

The OMV satellite servicing facilities are still the single servicing structure from the initial station. The OTV TDM and Centaur integrated support structure will not be needed on the growth Station. They will be dismantled after their missions have been performed. Some of the OTV TDM equipment such as the servicing beams and shelter components could be used to build up the operational maintenance facility. This area on the service structure could be used for other activities after the operational facility is completed.

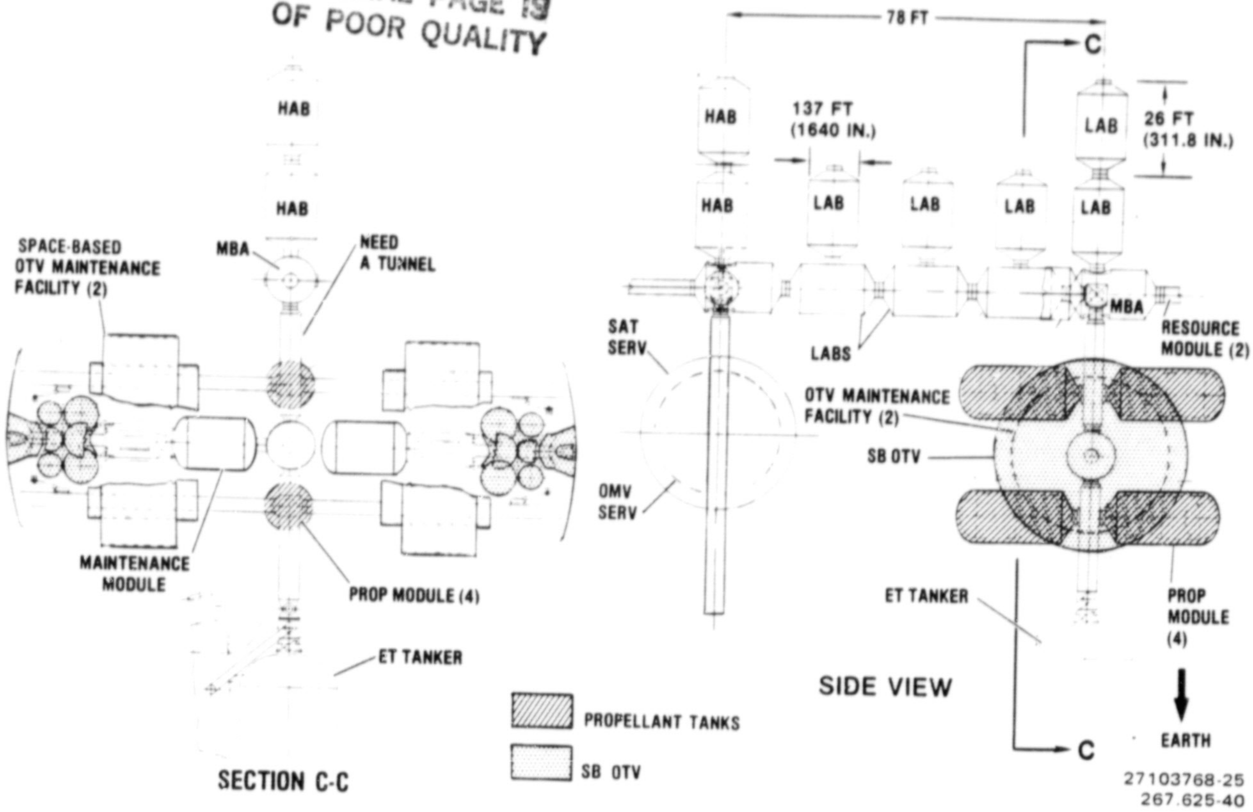

Figure 2-25. Growth Space Station (Alternative) OTV Servicing - Maintenance Module

A second servicing structure is attached to the second MBA to support the two OTV maintenance facilities including the two maintenance modules. A tunnel would be required in the servicing structure so that the crew could reach the maintenance module IVA. There would be an ET tanker docking port at the end of the servicing structure. The propellant tank modules are also attached to the servicing structure and the junction with the maintenance dock structure.

Again the servicing facilities for OTV/OMV/satellite servicing are of equal magnitude to the rest of the station and are a major design driver for the station concept.

2.4 MISSION TURNAROUND OPERATIONS

The turnaround operations required to totally support a space-based OTV at the Space Station are defined and analyzed in this section.

Figure 2-26 shows how we approached the space-based OTV operations analysis to make sure that we were thorough and complete in identifying functional requirements.

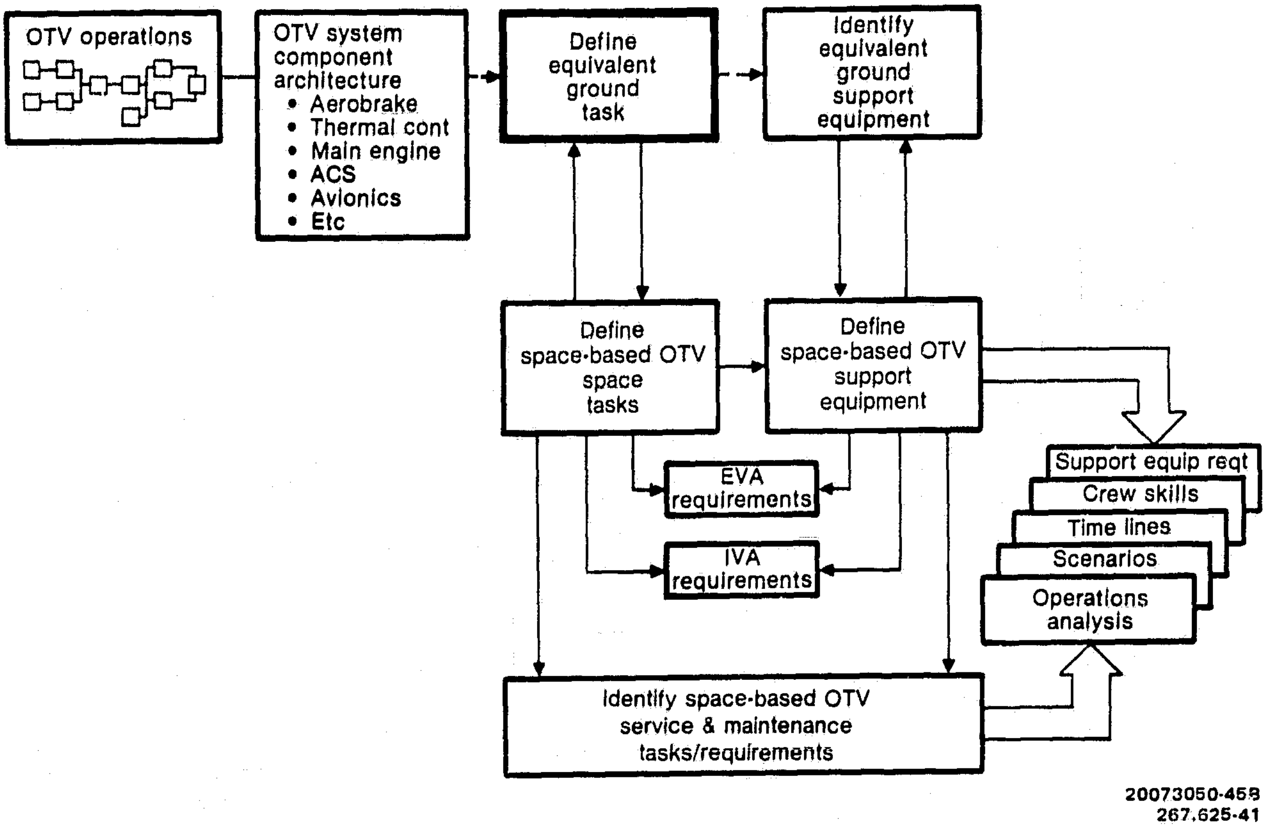

Figure 2-26. Space-Based OTV End-to-End Mission Operations Approach

The space-based OTV operations flow diagrams, which were blended with OTV and Space Station conceptual designs and architecture in an iterative manner, provided a means for identifying the OTV system functional task requirements. These functional tasks included maintenance operations that were expanded and refined as the system concept matured. The maintenance functions are one of the major elements of the space-based OTV operations involving IVA and EVA. Our approach to identifying these IVA/EVA operations and supporting crews, skills, equipment, and processes was directed at matching similar ground-based vehicle operations with our space-based OTV maintenance operations to assure a complete task breakdown. These tasks, in conjunction with a maintenance philosophy and EVA ground rules supported a comprehensive space-based OTV maintenance operations analysis.

The objective of generating this data is to identify the technology required to develop the capability of maintaining/servicing an OTV at a Space Station. The technologies required to be developed from the analyses performed in this task are identified in Section 5.

The operational ground rules for EVA listed in Table 2-28 are a combination of EVA ground rules, Space Station philosophies, and NASA references in the RFP. They formed the basis for determining EVA involvement in support of servicing and maintenance operations during this study.

Table 2-28. Space-Based OTV Operational Ground Rules for EVA

- A TRANSPORT SYSTEM WILL BE AVAILABLE FOR EVA CREW TRANSLATION TO WORK AREA
- EVA PERSONNEL CAN OPERATE SAFELY AROUND OTV & PROPELLANT TRANSFER AREA
- ON-SITE PROPELLANT LEAK DETECTION SYSTEM WILL PROVIDE DIRECT INFORMATION TO EVA PERSONNEL
- PLANS & PROCEDURES STORED IN COMPUTER
- INFORMATION UPDATES PROVIDED VIA HEADS-UP DISPLAYS
- ONE EVA (8-HOUR MAX) MISSION PER DAY PER CREW MEMBER
- MONITOR & CONTROL FOR EVA PROVIDED BY SPACE STATION CREW
- 2-MAN EVA OPERATIONS IS A REQUIREMENT
- EVA CONDUCTED IN BOTH LIGHT & DARK ENVIRONMENTS

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The servicing and maintenance operations capability will be dependent on Space Station IVA and EVA operations, and subsequently influenced by 1) the extent and capability of IVA/EVA personnel, 2) the extent and capability of the remotely operated handling and surveillance devices, and 3) the man/machine interface compatibility.

These ground rules therefore emphasize the availability of an advanced extravehicular maneuvering unit (EMU) with the following features:

a. No prebreathing requirement

b. Nonventing/regenerative thermal control

c. Regenerative CO_2 control

d. 100+ recharge battery

e. EVA computer information system

f. Head-up display

g. On-orbit maintainable

h. Advanced glove

An OTV maintenance philosophy encompassing Space Station operations was developed to help us focus on the essential elements of maintenance support requirements. This OTV maintenance philosophy is highlighted in Table 2-29. The maintenance philosophy is based on the three levels of maintenance described below.

Level I maintenance consists of the scheduled and unscheduled activities that occur on the vehicle while it is berthed in the Space Station maintenance dock.

Table 2-29. OTV Maintenance Philosophy

Three-level maintenance — based on level-of-repair analyses
- I OTV local maintenance
- II Space station maintenance of replaceable units
- III Return-to-earth maintenance

Stock spare parts based on reliability, criticality & cost
- Station storage vs Shuttle delivery

Stress modular construction for replacement capability

Provide operational flight instrumentation & built-in test
- Fault isolate to replaceable unit

Optimize EVA vehicle maintenance operations
- Consider safety in hazardous situations
- Tradeoff EVA vs support equipment
  - TV inspection
  - Robotic remove & replace

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Level II maintenance encompasses the off-vehicle repair of replaceable OTV components conducted at the Space Station. The OTV replaceable units will be dispositioned for return to Earth or repaired at the station to the extent possible within the test equipment, spares availability, and economic constraints.

Level III maintenance will involve normal Earth-oriented disposition for repair. An extensive analysis will ultimately provide the necessary repair or discard decision criteria.

Although three levels of maintenance were defined to understand the interrelationship of activities, the scope of the contract for this study requires that we look only at Level I maintenance activities at the Space Station. These Level I maintenace operations analyses provided sufficiently detailed data that was needed to drive out the Space Station accommodations and technologies required to support the space-based OTV.

The maintenance philosophy also stresses important maintainability features that a space-based OTV must have, and these features affect the operations analysis with respect to task definitions and the time it takes to do them. These maintainability features have been incorporated into our conceptual designs of the space-based OTV and Space Station, which include the modular concept for simple replacement of components. The modular configuration concept requires quick-disconnect interfaces and adequate built-in test capability to allow fault isolation to the replaceable unit.

We compiled an operations analysis data base as the study progressed.

The task analysis worksheet provided the medium for documenting and forming our data base used in the assessment of Space Station assets and technologies required to support a space-based OTV. Table 2-30 lists the basic information that was gathered and compiled in our task analysis worksheets.

Table 2-30. Information in Task Analysis Worksheets

- Equivalent ground tasks
  - Reusable stage (1975 state-of-art)
  - Centaur
- Space station tasks
- Support equipment requirements
- Task duration
- IVA crew requirements
- EVA crew requirements
- Man hours
  - Total per task
  - EVA per task

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As the functional tasks for OTV space-based operations were identified, the tasks were entered on the worksheets. The Space Station tasks were compared with equivalent ground tasks, where they existed, to assure the completeness of operational activities. Support equipment requirements, along with IVA and EVA crew requirements were established, then the task durations were estimated for each activity. The equivalent manhours were calculated and recorded and a separate listing was created to identify EVA manhour expenditures.

The analysis involved the examination of operations for the "shelter" and "maintenance module" configurations of the Space Station maintenance facility. After careful evaluation of the four alternative maintenance facility configurations, presented earlier in this report, the alternatives to be included in the operations analysis were narrowed by eliminating the "no shelter" and "pressurized hangar" configurations. We feel that these are not viable approaches for the space-based OTV maintenance facility. The reasoning behind the recommendation of the "shelter" and "maintenance module" configurations will be presented later, in Section 3.

The full complement of task analysis worksheets used in the operations analysis are in the appendixes. The functional tasks that make up the space-based OTV operations analysis at the Space Station are listed in Table 2-31. Task analysis worksheet examples have been extracted from our data base in the appendixes to use here in the text. We selected examples where the greatest task differences occur between the "shelter" and "maintenance module" configurations; that is, engine changeout and avionics removal and replacement. The examples that were selected for inclusion in the text are highlighted with an asterisk in Table 2-31.

Table 2-31. The Operations Analysis Functional Task Description

INITIAL MAINTENANCE FACILITY INSTALLATION
- SHUTTLE MISSION 1 – MAINTENANCE MODULE INSTALLATION & ACCESSORIES KIT OFFLOAD
- SHUTTLE MISSION 2 – TRUSS STRUCTURE INSTALLATION
- SHUTTLE MISSION 3 – SHELTER STRUCTURE & SUPPORT EQUIPMENT INSTALLATION
- SHUTTLE MISSION 4 – PROPELLANT FACILITY & REFRIGERATION/CONTROL UNIT INSTALLATION
- SHUTTLE MISSION 5 – PROPELLANT MODULE INSTALLATION

INITIAL OTV DELIVERY & ASSEMBLY

NORMAL SPACE-BASED OTV TURNAROUND

PERIODIC MAINTENANCE
- REMOVE & REPLACE FUEL CELL – SHELTER/MAINTENANCE MODULE CONFIGURATIONS
- REMOVE & REPLACE ENGINE – SHELTER CONFIGURATION*
- REMOVE & REPLACE ENGINE – MAINTENANCE MODULE CONFIGURATION*

UNSCHEDULED MAINTENANCE
- REMOVE & REPLACE AVIONICS MODULE – SHELTER CONFIGURATION*
- REMOVE & REPLACE AVIONICS MODULE – MAINTENANCE MODULE CONFIGURATION*
- REPAIR AEROBRAKE – SHELTER/MAINTENANCE MODULE CONFIGURATION
- REMOVE & REPLACE TANK MODULE – SHELTER/MAINTENANCE MODULE CONFIGURATION

*TASK ANALYSIS WORKSHEET EXAMPLES PROVIDED IN THE TEXT

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The worksheets reflect sufficient detail for identifying equipment requirements and establishing task durations. IVA notations are defined as follows:

- o IVA-Direct: Hands-on envolvement with the IVA task to be accomplished.
- o IVA-Remote: Remote control of equipment from within the IVA environment.
- o IVA-Support: Observation, communication or any other function required in support of EVA or IVA task accomplishment

The EVA notations of "active" and "standby" appear to be self-explanatory.

The total time and manhours required to accomplish each functional task are included on the worksheets. The total times are enclosed in a box in the appropriate column at the beginning of the worksheet for each functional task.

The worksheet examples appear in the operational analysis section for both the shelter and maintenance module configuration, which follow.

2.4.1 OPERATIONS ANALYSIS - SHELTER CONFIGURATION. The operations analysis for the space-based OTV maintenance facility, shelter configuration, that was conducted to determine the turnaround requirements for the OTV at the Space Station is presented here. To show how the operations analysis was conducted, we will present a sample of the data base that was compiled on the task analysis worksheets and the timelines that were derived from the data base.

2.4.1.1 Operations Task Analysis. Task analysis worksheets were used to collect and organize pertinent data as the tasks were identified, assessed, and developed. Figure 2-27 provides a sample worksheet that was used to determine requirements for engine removal and replacement. However, the worksheet shows only the engine removal operation, since it is a sample worksheet that is intended to show how the analysis was performed. All of the actual worksheets that were used in the analysis to determine the turnaround requirements can be found in the appendixes. The engine removal and replacement worksheet was selected as a sample because that operation provides the greatest difference in turnaround time and requirements between the shelter and maintenance module configuration.

In the shelter configuration the engine is replaced in the nonpressurized environment of the maintenance dock/shelter area using remotely controlled equipment with EVA assistance. In the maintenance module configuration, the operation is accomplished totally within the shirtsleeve environment by hands-on crew involvement using directly controlled equipment.

The tasks were defined in sufficient detail to allow identification of necessary equipment and the assessment of time expenditures. We attempted to be conservative in the assignment of function durations. For example, when we estimated that a remote manipulator would operate at a speed of 1 foot every 2 seconds for a distance of 60 feet, we assigned 15 minutes to the function duration, not 2 minutes. We took into account the probable coordination and communication time that might be required by human operators. We also provided time, where it was possible, for removing the EVA crew to a safe area, while potentially hazardous equipment was being operated.

The avionics removal and replacement operation depicted in Figure 2-28 is another functional task that provided time and requirement differences between the recommended maintenance facility configurations. The avionics modules are removed and replaced using remotely controlled equipment without EVA involvement in the shelter configuration. In the maintenance module configuration they are replaced directly by the IVA crew within the shirtsleeve environment.

2.4.1.2 Operation Timelines. The timelines for the shelter configuration were derived from the information contained in our task analysis worksheet data base. A normal space-based OTV turnaround timeline is presented in Figure 2-29. A normal turnaround is one where the vehicle returns to the Space Station from a good flight without faults and does not require periodic maintenance.

The normal OTV turnaround timeline begins when the OTV approaches the Space Station within a specified distance (we are currently using 1 mile as the distance) to allow OMV rendezvous and docking with the OTV. The OMV will maneuver the OTV for capture with the station RMS, which will be used to place the OTV in the berthing structure.

The complete OTV turnaround at the Space Station will require 4 working days and dedicated IVA crew. EVA will not be required for normal turnaround operations. The total elapsed task time is 34 hours and 50 minutes.

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Ground Task	Space Station Task	Support Equipment Requirements	Function Duration	IVA			EVA		Man-hours	
				Direct	Remote	Support	Active	Standby	Total	EVA
1.1.11 Accomplish scheduled maintenance propulsion system *Procedure HPS 1-00347	• R/R engine		18:40						66:30	25:20
— Review procedures	— Query computer & review maintenance plan	Computer system	1:00	4					4:00	
— Obtain planning paper	— Bring all systems on line & position equipment	Computer system, facility control panels	1:00 ‖		1 ‖	1			4:00	
— Pick up handling tool with overhead crane	— perform pre-EVA tasks	EMU, airlock system, EVA tools	1:00	2	1					
— Position crane over engine	— Translate EVA crew to work area	Cherry picker system, lighting, CCTV, communications	:15			1	2		:45	:30
	— Attach rail truss extender to aerobrake	Rail truss extender	:15			1	2		:45	:30
	— Release aerobrake from OTV	EVA type latches	:30			1	2		1:30	1:00
— Remove plumbing & electrical wiring	— Translate EVA crew to safe area		:05			1	2		:15	:10
— Drain lines & reduce pressure to zero	— Extend rail truss with aerobrake		:05		1	1		2	:20	:10
— Disconnect 12 plugs & tie back	— Translate EVA crew to engine work area		:05			1	2		:15	:10
— Install handling tool on engine	— Attach crane to engine	Scissor crane, handling adapter	:30		1		2		1:30	1:00
— Support engine weight with crane										

*Centaur procedures

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Figure 2-27. Task Analysis Worksheet for Remove and Replace Engine in Shelter (Sheet 1 of 2)

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Ground Task	Space Station Task	Support Equipment Requirements	Function Duration	IVA			EVA		Man-hours	
				Direct	Remote	Support	Active	Standby	Total	EVA
— Remove 2 actuators	— Release engine/OTV interface	EVA quick disconnect latches	1:00			1	2		3:00	2:00
— Remove 4 engine mounting bolts	— Translate EVA crew to safe area		:05			1	2		:15	:10
— Verify engine free for hoisting										
— Raise engine & place on trailer	— Remove engine & transfer to RMS	RMS	:30 ‖		1	1 ‖		2	2:00	1:00
	— Translate EVA crew to work area & inspect OTV interface		:30			1	2			
	— Translate engine to holding fixture	Engine holding fixture	:20 ‖		1	1		2	1:20	:40
	— Translate EVA crew to engine storage area		:20				2			
	— Position engine in holding fixture		:20		1	1		2	1:20	:40
— Secure engine to trailer	— Secure engine in holding fixture & release RMS		:30			1	2		1:30	1:00
— Install support to LO_2 & fuel lines	— Clean & secure work area		:30		1		2		1:30	1:00
— Cover gimbal block & tie	— Translate EVA crew to station		:15			1	2		:45	:30
	— Perform post-EVA tasks		1:00 ‖	2		1 ‖			3:15	
	— Deactivate & secure all systems		:15		1	1				

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Figure 2-27. Task Analysis Worksheet for Remove and Replace Engine in Shelter (Sheet 2 of 2)

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Ground Task	Space Station Task	Support Equipment Requirements	Function Duration	IVA			EVA		Man-hours	
				Direct	Remote	Support	Active	Standby	Total	EVA
1.1.8 Perform unscheduled maintenance & refurbish all systems Detail not available	• Perform unscheduled maintenance • R/R avionics module		2:45						5:30	
	— Bring all systems on line	Computer system, maintenance facility & controls	:15		1	1			:30	
	— Query computer & review maintenance plan		:15		1	1			:30	
	— Orient RCA in appropriate shelter quadrant	RCA & control panel, CCTV, lighting	:10		1	1			:20	
	— Extend RCA to module		:05		1	1			:10	
	— Remove insulation panel	RCA adapter	:10		1	1			:20	
	— Remove avionics module		:10		1	1			:20	
	— Inspect OTV module interface	CCTV	:05		2				:10	
	— Translate RCA & stow failed module	Module holding fixture	:15		1	1			:30	

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Figure 2-28. Task Analysis Work Sheet for Remove and Replace Avionics Module in Shelter (Sheet 1 of 2)

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Ground Task	Space Station Task	Support Equipment Requirements	Function Duration	IVA			EVA		Man-hours	
				Direct	Remote	Support	Active	Standby	Total	EVA
	— Load RCA with replacement module		:05		1	1			:10	
	— Orient RCA in appropriate shelter quadrant		:10		1	1			:20	
	— Extend RCA with module		:10		1	1			:20	
	— Install replacement module		:15		1	1			:30	
	— Replace insulation panel		:10		1	1			:20	
	— Perform checkout		:10		1	1			:20	
	— Retract & stow RCA		:10		1	1			:20	
	— Enter completed task in maintenance plan		:05		1	1			:10	
	— Deactivate shelter facilities		:05		1	1			:10	

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Figure 2-28. Task Analysis Worksheet for Remove and Replace Avionics Module in Shelter (Sheet 2 of 2)

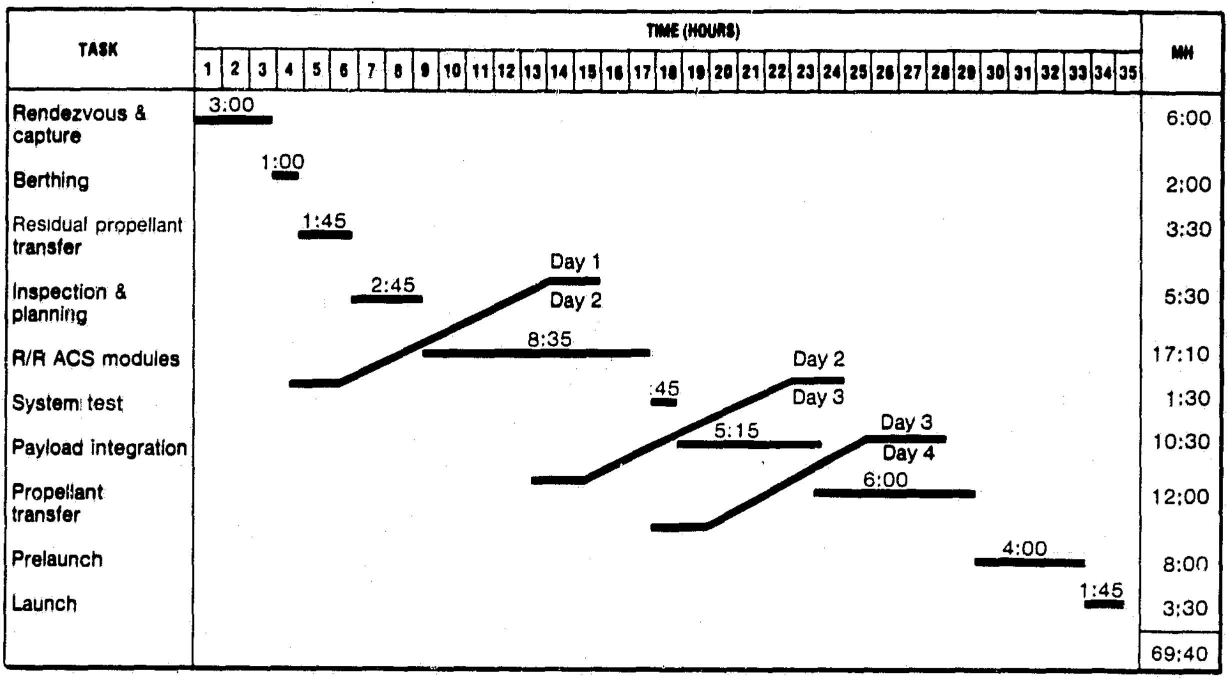

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Figure 2-29. OTV Normal Turnaround for Shelter Configuration with No EVA

The prelaunch and launch times were derived from the actual timelines established for the Shuttle/Centaur International Solar Polar Mission (ISPM). The ISPM nominal flight operations sequence of events for Centaur deployment and applicable free flight can be found in the appendixes.

Figure 2-30 reveals the timelines for OTV periodic and unscheduled maintenance for the shelter configuration. The timelines are for maintenance tasks that are not considered as part of the normal turnaround cycle because they do not occur on each and every mission. Periodic maintenance will occur on a timely basis; e.g., engine changeout after 10 missions or some predetermined time of operation, fuel cell servicing after five missions, etc. Unscheduled maintenance is performed as a result of equipment failure or damage and occurs generally on a random basis. The operations analyses were based on serial operations. Parallel operations would increase manloading, equipment, and power requirements depending on the mix of maintenance tasks to be accomplished. Parallel operations would also increase levels of concern for safety, especially with EVA personnel and equipment operating in the same work area at the same time.

The analysis reveals that engine and tank module changeouts will each require 2 days to accomplish the task with EVA involvement. Aerobrake damage repair times are difficult to establish; however, we have estimated that 1 day of EVA operations would provide for minor damage repair. In any case, the aerobrake could be removed and replaced within a 1 day operation. The fuel cells/batteries and avionics modules can be replaced utilizing IVA remotely controlled equipment and can each be accomplished in less than 3 hours.

2.4.2 OPERATIONS ANALYSIS - MAINTENANCE MODULE CONFIGURATION. The operations analysis performed on the maintenance module configuration to determine the turnaround requirements for the OTV at the Space Station is contained in this section. We have provided a sample of the data base that was compiled on the task analysis worksheets and the associated timelines.

2.4.2.1 Operations Task Analysis. A sample task analysis worksheet for engine remove and replace operations for the maintenance module configuration is contained in Figure 2-31. The tasks progress through the engine removal operation to reveal some of the differences from the shelter configuration operation. The OTV must be mated with the maintenance module interface to allow IVA access to the engine work area, where the engine is removed in the shirtsleeve environment. The operation does not require EVA assistance.

The avionics modules are replaced within the same shirtsleeve environment as shown in Figure 2-32.

2.4.2.2 Operation Timelines. The timeline for a normal space-based OTV turnaround operation is contained in Figure 2-33.

The normal OTV turnaround timeline for the maintenance module configuration is essentially the same as that for the shelter configuration, and varies only by 3 hours and 20 minutes. This additional time is required for OTV/maintenance module mating and demating. Four working days are required for space-based OTV turnaround at a Space Station and, again, EVA is not required for normal OTV turnaround.

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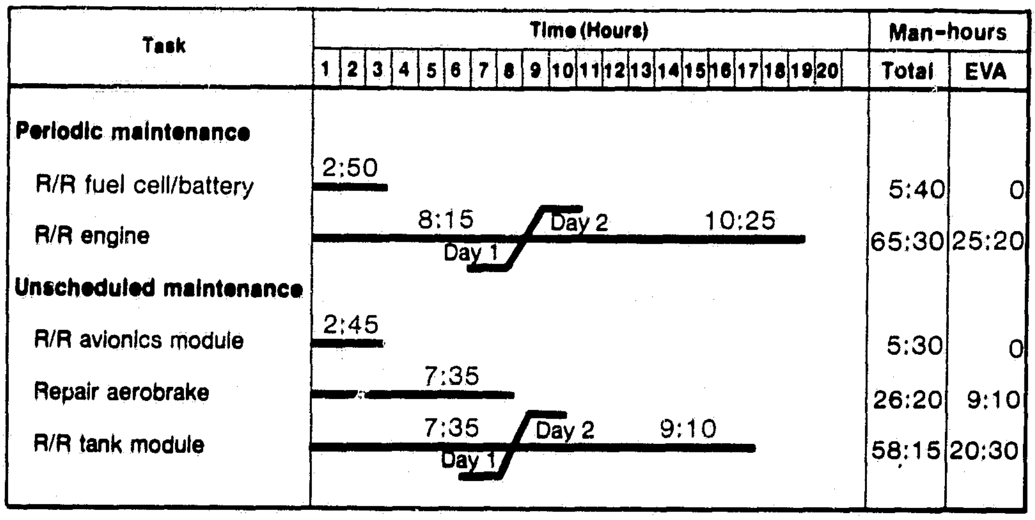

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Figure 2-30. OTV Periodic and Unscheduled Maintenance for Shelter Configuration

Figure 2-34 presents the OTV periodic and unscheduled maintenance timelines for the maintenance module configuration.

The maintenance module configuration eliminates the need for EVA operations on engine changeout and reduced task duration time from 2 days to 1 day. The avionics module remove and replace times are reduced from 2 hours and 45 minutes to 1 hour and 40 minutes. All other times and EVA involvement remain the same as that for the shelter configuration.

2.4.3 INITIAL OTV DELIVERY TIMELINES. Figure 2-35 presents the timelines for initial OTV delivery and assembly at the Space Station. The timelines were derived from the task analysis worksheet data base contained in the appendixes.

The timeline shows the number of days, tasks, and manhours required to assemble and check out the OTV on initial delivery to the Space Station in the vertical columns and presents the direct task times in hours on the horizontal axis. The space-based OTV can be delivered on one Shuttle flight and rendered operational within 6 working days. The initial OTV delivery operations will be essentially the same for both the shelter and the maintenance module configurations. The total manhours required to accomplish this delivery task are 178:00 manhours, including 58:30 manhours EVA. The longest operational day is dedicated to engine installation and the length of the operation is due in part to the aerobrake installation.

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Ground Task	Space Station Task	Support Equipment Requirements	Function Duration	IVA			EVA		Man-hours	
				Direct	Remote	Support	Active	Standby	Total	EVA
1.1.11 Accomplish scheduled maintenance propulsion system	• Scheduled maintenance									
	• R/R engine		$\boxed{9:05}$						$\boxed{18:10}$	
	— Bring all systems on line	Computer system, control panels	:15	2					:30	
*Procedure HPS 1-00347	— Query computer & review maintenance plan	Computer system	:30	2					1:00	
— Review procedures	— Determine that OTV engine is free of contaminants	Remote propellant sensors	:15		1	1			:30	
— Obtain planning paper	— Alert personnel to exit OTV interface area	Caution & warning system, maintenance module airlock	Δ	2					—	
— Pick up handling tool with overhead crane										
— Position crane over engine	— Withdraw OTV from maintenance module	Pressurization system, berthing carriage & controls	1:15 ‖		1	1			2:30	
— Remove plumbing & electrical wiring	— Retract shelter	Shelter mobility & controls	:15		1	1				
— Drain lines & reduce pressure to zero	— Rotate OTV 180 deg & orient engine to maintenance module	Rotational berthing mechanism & control	:20		1	1			:40	
— Disconnect 12 plugs & tie back	— Move OTV towards maintenance module		:10 ‖		1	1			:30	
	— Extend shelter		:15		1	1				

*Centaur procedures

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Figure 2-31. Task Analysis Worksheet for Remove and Replace Engine in Maintenance Module (Sheet 1 of 2)

Ground Task	Space Station Task	Support Equipment Requirements	Function Duration	IVA			EVA		Man-hours	
				Direct	Remote	Support	Active	Standby	Total	EVA
— Install handling tool on engine — Support engine weight with crane	— Engage OTV aft collar & maintenance module interface	Pressurized interface maintenance module	:15		1	1			:30	
— Remove 2 actuators	— Check pressure seal & pressurize	Pressurization system	1:15		1	1			2:30	
— Remove 4 engine mounting bolts	— Attach crane to engine	Scissor crane, handling adapter	:15	2					:30	
— Verify engine free for hoisting	— Disengage engine/ OTV interface	Tools, quick disconnects	:30	2					1:00	
— Raise engine & place on trailer	— Remove engine from OTV & move to holding fixture		:15	2					:30	
— Secure engine to trailer	— Place engine in holding fixture & secure	Engine holding fixture	:15	2					:30	
— Install support to LO_2 & fuel lines — Cover gimbal block & tie	— Inspect OTV engine interface		:10	2					:20	

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Figure 2-31. Task Analysis Worksheet for Remove and Replace Engine in Maintenance Module (Sheet 2 of 2)

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Ground Task	Space Station Task	Support Equipment Requirements	Function Duration	IVA			EVA		Man-hours	
				Direct	Remote	Support	Active	Standby	Total	EVA
1.1.8 Perform unscheduled maintenance & refurbish all systems	• Perform unscheduled maintenance									
Detail not available	• R/R avionics module		$\boxed{1:40}$						$\boxed{3:20}$	
	— Bring all systems on line	Computer system	:15	2					:30	
	— Query computer & review maintenance plan		:15	2					:30	
	— Obtain tools from tools storage kit	Tool kit	:03	1		1			:06	
	— Locate avionics module on OTV		:02	1		1			:04	
	— Remove insulation panel	Quick disconnects	:05	2					:10	
	— Insert extraction tool & release module	Extraction tool	:01	2					:02	
	— Remove avionics module		:02	2					:04	
	— Place module in repair storage rack	Storage fixtures	:05	1		1			:10	

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Figure 2-32. Task Analysis Worksheet for Remove and Replace Avionics Module in Maintenance Module (Sheet 1 of 2)

Ground Task	Space Station Task	Support Equipment Requirements	Function Duration	IVA			EVA		Man-hours	
				Direct	Remote	Support	Active	Standby	Total	EVA
	— Obtain new module from spares rack	Spares holding fixtures	:05	1		1			:10	
	— Insert new module in OTV		:10	2					:20	
	— Latch & secure module in OTV		:03	2					:06	
	— Inspect avionics installation		:05	2					:10	
	— Replace insulation panel		:05	2					:10	
	— Inspect insulation replacement		:02	2					:04	
	— Clear area & return tools to kit		:05	1		1			:10	
	— Perform operational test		:10		2				:20	
	— Enter completed task in maintenance plan		:05	1		1			:10	
	— Deactivate all systems		:02	1		1			:04	

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Figure 2-32. Task Analysis Worksheet for Remove and Replace Avionics Module in Maintenance Module (Sheet 2 of 2)

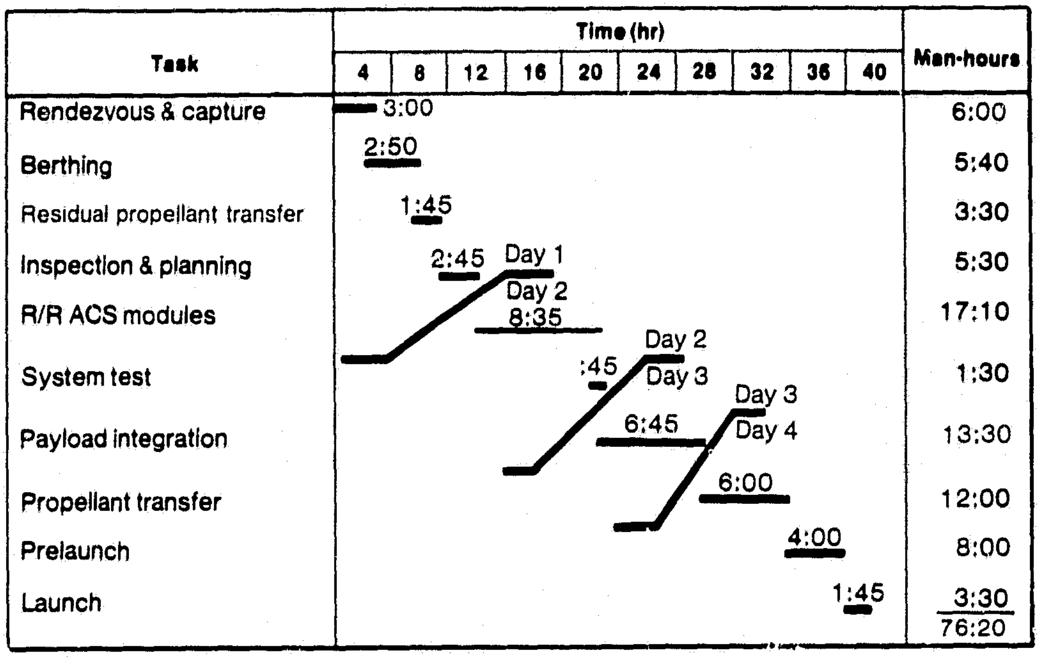

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Figure 2-33. OTV Normal Turnaround Time for Maintenance Module Configuration with No EVA

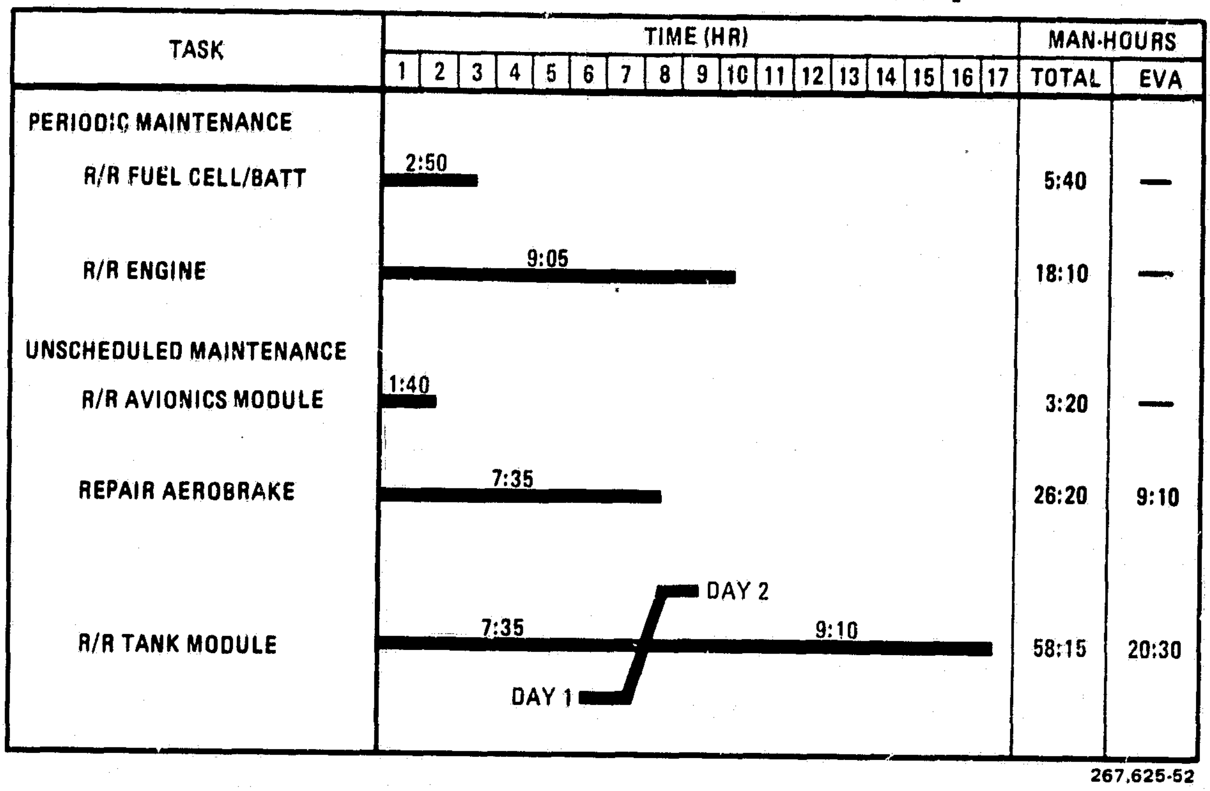

Figure 2-34. OTV Periodic and Unscheduled Maintenance Timelines for Maintenance Module Configuration

2.5 COMPARISON OF GROUND-BASED VERSUS SPACE-BASED TASKS

We will now compare the space-based OTV turnaround operations with that of a ground-based vehicle turnaround operation. The assessment of ground-based operations were presented in Section 2.2, which revealed the tasks and time required to turnaround a ground-based vehicle. In Section 2.4, we presented the detailed analysis for space-based OTV operations as documented on our worksheets, which provided the data base that was necessary to produce the space-based OTV timelines. This space-based OTV information is now listed in Table 2-32 to correspond with the summary ground-based-tasks to show a comparison between the two different modes of operation.

It becomes apparent that all tasks do not correlate directly and that they are not accomplished in the same manner because of the obvious time differences. For instance, Task No. 1.1.1 takes eight men 8 hours to analyze data and prepare a maintenance plan on the ground, whereas the space-based OTV concept provides built-in test equipment on the vehicle and the onboard computer system determines the fault status and transfers the information to the Space Station. At the Space Station, a predetermined basic maintenance plan is displayed, based on the acquired fault status data. The basic plan can be modified by the crew through data entry terminals, but the basic plan has already been thought out and is presented as a menu. A standard maintenance plan would be presented for a normal turnaround. When faults are detected, the plan would incorporate appropriate unscheduled tasks as required.

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DAY	TASK	TIME (HOURS)	MAN HOURS Total	MAN HOURS EVA
1	Shuttle/station operations	2:00	6.00	0
	Offload & position OTV core section	.50	1:35	0
	Assemble tank trusses to core section	5:35	16:15	6:40
	Transfer core section to maintenance dock	2:00	4:00	0
2	Assemble 1st tank module to OTV	9:20	32:30	12:10
3	Assemble 2nd tank module to OTV	9:20	32:30	12:10
4	Deploy aerobrake	8:30	28:00	8:20
5	Assemble engine & aerobrake to OTV	10.35	37:55	15:10
6	Inspect OTV assembly	4:00	13:45	4:00
	Extend shelter to cover OTV	:15	:30	0
	Perform system operational testing	2:00	4:00	0
	Deactivate & stow all systems	.30	1:00	0
			178:00	58:30

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Figure 2-35. Initial OTV Delivery Timelines for Shelter and Maintenance Module Configurations

Another labor intensive example is provided in Task 1.1.3, where the ground-based vehicle is transferred to the maintenance-test stand after it has been downloaded from the Shuttle. The space-based OTV, on the other hand, does not require this time consuming labor intensive handling; it figuratively lands at the maintenance facility. The Space Station berthing interface also provides automatic mating of quick-disconnect electrical and fluid lines to provide for data acquisition and propellant transfer.

These examples of differences between ground-based versus space-based operations provide some insight as to the efficiency of the space-based OTV operation that is provided by careful design. Other differences between the two operations will be examined later when we make a space-based OTV turnaround assessment to be compared with the ground-based assessment presented in Section 2.2.

A summation of the total task times for both operations is provided in Table 2-33.

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Table 2-32. Comparison of Ground-Based Versus Space-Based Tasks

Task No.	Reusable Ground-Based Vehicle — Task	Time (hr)	MH	Space-Based OTV Equivalent Task	Time (hr)	MH
3.1.1	Safe stage	:30	2:30	Transfer OTV propellants to station	1:45	3:30
3.1.2	Purge main propellant tanks	6:00	48:00			
3.1.3	Remove flight data recorder tapes	:30	1:00			
3.2.1	Remove stage from orbiter	8:30	110:30			
3.3.1	Transfer stage to maintenance facility	2:00	18:00			
1.1.1	Analyze data & prepare maintenance plan	8:00	64:00	Query computer about fault status	:15	:30
1.1.3	Transfer stage from pallet to maintenance & test stand	5:00	365:00	OTV docks at maintenance facility (includes rendezvous & capture)	3:40	7:20
1.1.4	Remove stage access doors & connect GSE	3:00	68:00	Automatic connection through berthing interface	**	
1.1.5.1	Inspect structural elements & thermal control	11:00	288:00	Visual inspection (TV)	2:00	4:00
1.1.5.2	Inspect tanks, supports & interior			Visual inspection (TV)		
1.1.5.3	Inspect MLI & thrust structure			Visual inspection (TV)		
1.1.5.4	Inspect docking mechanism			Visual inspection during capture before docking (TV)		
1.1.5.5	Inspect avionics & flight control units			Visual inspection (TV)		
1.1.5.6	Inspect engine fluid & pressure lines			Visual inspection (TV)		
1.1.5.7	Inspect fuel cells			Visual inspection (TV)		
1.1.6.1	Perform scheduled checkout & fault isolate	4:00	32:00	Initiate test routine & fault isolate	*	
1.1.6.2	Perform leak check on LH_2 & LO_2 tanks & engine	16:00	79:00	Monitor for propellant leakage	:15 30:45	:30
1.1.6.3	Inspect stage/orbiter interface (post-flight fault ISO)					
1.1.7	Review inspection & checkout results & complete maintenance plan	8:00	80:00	Formulate integrated maintenance plan (partially automated function)	:30	1:00
1.1.8	Perform unscheduled maintenance	8:00	160:00	Perform unscheduled maintenance	Avg *(2:45)	Avg (8:30)
1.1.9	Perform scheduled maintenance — structures			Perform scheduled maintenance	8:35	17:10
1.1.10	Perform scheduled maintenance — avionics	20:00	842:00			
1.1.11	Perform scheduled maintenance — propulsion					
1.1.12	Perform scheduled maintenance — thermal control					
1.2.1	Mate stage & stage/orbiter adapter	1:00	8:30			
1.2.2	Check out docking mechanism	5:00	50:00			
2.1.5	Prepare for storage	Not in time line		Deactivate & stow all systems	**	
2.1.6	Monitor stage in storage					
2.1.7	Remove from storage			Activate OTV & maintenance facility	**	
2.1.8	Accomplish mission-peculiar preparations			(Not defined at this time)		
2.1.9	Perform systems test	16:00	320:00	Perform system operational testing	:45	1:30
2.1.10	Correct faults	Not in time line		Perform corrective maintenance	*	
2.1.11	Reverify system after correction	Not in time line		Perform system operational testing after corrective maintenance	*	
2.1.12	Secure from system test	7:30	77:30			
2.2.5	Mate stage & spacecraft	3:30	52:30	Mate payload to OTV	4:15	8:30
2.2.6	Verify stage/spacecraft interface	1:00	8:00	Verify OTV/payload interface	:15	:30
2.2.7	Perform integrated system test	Not in time line		Perform payload/OTV integration test	:30	1:00
2.3.1	Transport payload (stage & spacecraft) to orbiter	3:30 6:30	21:00 77:00			
2.3.2	Install in orbiter	2:00	24:00			
2.3.3	Verify orbiter/payload interface	5:00	25:00			
2.3.4	Conduct integrated systems test (ORB/PL)	1:00	4:00			
2.3.5	Check status — stage/shuttle interface (after shuttle up-load)					
2.4.1	Conduct orbiter/payload integrated test	3:00	12:00			
2.4.3	Conduct launch readiness test (stage)	1:00	4:00	Perform prelaunch operations	4:00	8:00
2.4.4	Load propellants & pressurants	4:00	20:00	Transfer propellants from station to OTV	6:00	12:00
2.4.5	Conduct terminal countdown	0:25	1:30	Launch OTV/payload	1:45	3:30

* Not in normal turnaround
** Incorporated in other task

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Table 2-33. Comparison of Ground-Based and Space-Based Total-Task Times

ITEM	TASK-TIME	MANHOURS	AVERAGE NO. OF MEN PER TASK	TOTAL NO. OF MEN REQUIRED FOR ALL TASKS
ALL GROUND-BASED OTV TASK-TIMES LISTED	152:45	2534:30	16.6	35
SPACE-BASED OTV AVG TASK-TIMES FOR NOMINAL 20 MISSION YEAR	40:01	85:50	2.2	4
GROUND-BASED OTV TASK-TIMES THAT CORRELATE WITH SPACE-BASED OTV NORMAL TURNAROUND TASKS	90:45	1097:00	12.1	35
SPACE-BASED OTV TASK-TIMES FOR NORMAL TURNAROUND (SHELTER CONFIGURATION)	34:50	69:40	2.0	2
NOTE:				
F-16 FIGHTER AIRCRAFT NO-FAULT TURNAROUND (INCLUDES FUELING & MUNITION UPLOAD)	:15-:30			
F-16 FIGHTER AIRCRAFT NOMINAL TURNAROUND	1:30			

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The accumulative task times that are required to perform a turnaround operation on ground-based and space-based vehicles are presented here with the associated manhours and average manloading requirements. A column to show the total number of men required to perform all tasks has been included, which takes into account the peak loading and total skill level requirements. The 153 hour task time includes all tasks required for ground-based operations, whereas the 40 hour task time was derived as an average for a nominal 20 mission year. We have incorporated expected periodic and unscheduled maintenance activities in the nominal 20 mission per year model and the time presented in the figure is the average of these space-based OTV task times.

All ground-based tasks are not required for space-based OTV operations; therefore, we have also presented ground-based task times that correlate with space-based OTV normal turnaround tasks to provide for a more realistic assessment. As stated earlier, a normal turnaround is accomplished on a vehile that is fault free and does not require periodic maintenance. The space-based OTV normal turnaround task time is about 38% of that required for corresponding ground-based operations and can be accomplished with two men, as compared with the 35 men allotted for ground-based operations. The space-based personnel, however, are not alone. Table 2-34 shows that a crew of 35 is required to support the space-based operations. This does not include indirect support personnel. The ground personnel requirements were arrived at independently and the results were found to match the Ground-Based reusable Vehicle Study (Reference 1) program support personnel requirements.

Table 2-34. Space-Based OTV Ground Support Personnel Requirements

Discipline	No. of Support Crew
Structures Engineer	1
Thermal Engineer	1
Propulsion Engineer	2
Avionics Engineer	8
Mission Planning	3
Maintenance Planning	2
Logistics	8
Mission Operations Support	6
Payload Interface Specialist	2
Maintenance Facility Specialist	2
Total ground support crew	35

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The F-16 fighter aircraft turnaround times have been included in Table 2-33 to show what is being accomplished today with current operational fighter aircraft that have been designed with some attention toward maintainability. The no-fault turnaround time of 15 minutes applies if the aircraft is fueled and uploaded with munitions at the same time and 30 minutes if they are done separately.

The disparity between the task times and man level requirements to perform ground-based and space-based operations has been partially accounted for in the examples for task comparisons. Further examination of the differences is now provided in the space-based OTV turnaround assessment listed in Table 2-35.

The assessment of Space Station operations, maintenance philosophy, and space-based OTV design features was conducted to determine what the differences were from a ground-based system that affect the turnaround times and crew requirements. The results of the assessment are presented to provide some of the reasons why a space-based OTV turnaround operation can be accomplished in less time and with considerably fewer men than a ground-based operation.

The rationale presented in Table 2-35 aligns almost directly with the ground-based vehicle turnaround assessment in Table 2-36, although the two methods of operation are contrastingly different.

Table 2-35. Space-Based OTV Turnaround Assessment

- Vehicle is fully checked on ground with planned assembly at the space station
- Turnaround operations are optimized by restriction to Level I maintenance
- Maintainability is a primary vehicle/system design requirement
  - Accessibility for remote & EVA operations
  - Modular construction of space-based OTV simplifies & speeds up replacement process
- Checkout accomplished with vehicle built-in test capability
  - Vehicle computer system evaluates & registers fault during mission
  - Vehicle status relayed to station via RF datalink or through data bus interconnect after berthing
  - Interfaces automatically connected during berthing operations
- Computer system analyzes & displays vehicle status & presents basic maintenance plan
- Majority of maintenance tasks are accomplished by semiautomatic (or robotic) equipment
- Inspection by TV without tear down operation
- No shuttle interface operations required beyond initial delivery
- Vehicle is not subjected to space—Earth transition environment
- Vehicle berths at maintenance facility
- Operations philosophy assumes vehicle is operational after good flight with aid of instrumentation & computer assessment
- Vehicle does not need to be dismantled after each mission, which minimizes damage due to maintenance operations

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The space-based operations philosophy supported by the corresponding design of the space-based OTV system accounts for a large portion of the disparity. The vehicle is assumed to be operational after a good flight and does not need to be dismantled for inspection and further maintenance unless the onboard instrumentation indicates a fault. Then, Level I maintenance is performed to remove and replace quick-disconnecting modules. The majority of these maintenance tasks is systematically accomplished remotely, utilizing semiautomatic or robotic equipment.

The space-based OTV also does not require repetitive upload and download operations with the Shuttle. The space-based OTV is initially received at KSC where it is checked out and prepared for launch on-board the Shuttle for delivery to the Space Station. However, once the space-based OTV has been delivered and assembled at the Space Station, the vehicle does not return to Earth. This means that the space-based OTV is not continually subjected to space-Earth transition environments before and after every mission. The OTV remains in the relatively benign environment of space.

Table 2-36. Ground-Based Vehicle Turnaround Assessment

- Ship, integrate & launch status has not been attained
  - Tendency to ship short & assemble missing parts later
  - Requires some disassembly & component checkout
  - Assumes man can compensate for system shortcomings
- Vehicles designed primarily for performance optimization
  - Maintainability & accessability not a design driver beyond providing access panels
- Checkout accomplished with GSE external to vehicle
  - Requires multiple interfaces (manual connection)
- Personnel required to analyze data & write maintenance plan
- Preventive & corrective maintenance accomplished manually
- Inspection requires dismantling to verify vehicle integrity
- Operation requires download, upload & integration with shuttle
- Operation requires transport & interface with maintenance facility
- QA & safety support required because of dismantling process & personnel involvement

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2.6 ACTIVATION OF SERVICING FACILITIES PRIOR TO IOC

Our analysis of the Space Station operations encompassed the installation of the maintenance module configuration of the OTV maintenance facility, which is contained as part of the data base on the task analysis worksheets in the appendixes. The results of the operations analysis on OTV maintenance facility installation are listed in Table 2-37. The list provides information on the number of Shuttle flights required to deliver the facility, definition of the Space Station components to be delivered, the number of days the Shuttle will be committed for each mission, the total offload and facilities installation time required, and the expected Shuttle load factor for weight and volume. It was assumed that all maintenance facility components would be delivered from Earth. However, it is acknowledged that some components of the space-based OTV TDM may be used to make up the operational configuration of the maintenance facility.

It has been estimated that delivery of one OTV maintenance facility to the early Space Station will require five Shuttle flights and a total Shuttle commitment of about 11 days. It is envisioned that an equipment accessories kit will be delivered on the first flight, along with the maintenance module. The accessories kit will contain support equipment to be installed in the maintenance facility, later on flight 3, once the shelter structure is in place. The accessories kit may later be used as a storage structure for OTV components.

The OTV maintenance facility will require about 21 working days for installation.

Table 2-37. Pre-IOC Space Station Maintenance Facility Installation

Shuttle Flight	Station Components	Shuttle Commitment (days)	Total Offload & Installation Time (days)	Shuttle Load Factor	
				Vol(%)	Wt(%)
1	Maintenance module & accessories kit	1	2	66	28
2	Truss structures	2	2	70	9
3	Shelter structure & support equipment installation	6	12	75	10
4	Propellant module & refrig/control unit	1	3	100	100
5	Propellant module	1	2	66	100

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2.7 FLEET OPERATIONS REQUIREMENTS

A review of the operations analysis data base allowed the formulation of space-based OTV fleet operations requirements. Table 2-38 lists OTV fleet operations requirements and shows how many flights per year that one space-based OTV can accommodate.

It is estimated that one OTV can perform 24 missions per year, based on the 4-day normal turnaround time established in our analysis. Two days are provided for OTV maintenance, either periodic or unscheduled, and 1 extra day for contingency operations. The maintenance operations timing depends, of course, on spare components being available at the Space Station when maintenance is required. The 7-day total turnaround time at the Space Station, coupled with a 7-day mission will support 24 flights per year. Therefore, one OTV could support the STS Rev. 6 mission model requirements, provided that the missions can be scheduled to coincide with the OTV turnaround cycle.

The solar system missions are a critical factor in the scenario and may require one additional OTV at the Space Station to meet reusable mission requirements.

The Shuttle/Centaur vehicle should be considered for use on solar system expendable missions.

Table 2-39 lists our recommendation for a two OTV fleet commitment to the Space Station in support of all reusable missions. Rescue and retrieval missions have not been clearly defined; however, it is apparent that some vehicle should be on standby during manned missions to provide for rescue operations. An OTV on a normal unmanned mission, unable to return to the station, could also be retrieved with the second OTV.

Table 2-38. OTV Fleet Operations Requirements

- One OTV can accommodate 24 reusable missions per year
  - 7-day space station turnaround (assumes dedicated crew and allows 2 days for engine or tank remove & replace)
- STS Rev. 6 mission model requirements

Year	1994	1995	1996	1997	1998	1999	2000
Mission totals	21	15	19	19	20	9	18
Solar system missions	2	1	1	1	1	1	

- Assume missions can be scheduled to fit OTV turnaround routine
- Solar system missions require critical window launches and may require expendable delivery

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Table 2-39. OTV Fleet Recommendations

Two-OTV fleet to support reusable missions
- One OTV to accommodate basic missions
- One OTV for contingency operations
  - Critical window support
  - Rescue & retrieval

Two-OTV space station facilities
- One full-up maintenance facility
- One docking/storage facility

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A fleet of two OTVs would require two OTV Space Station facilities to accommodate the vehicles. One of the OTV facilities would be a fully functioning maintenance facility as described in this study. A second OTV facility would be needed to provide for storage of a second OTV. This would be a dormant OTV facility that would consist of a bare truss structure to hold the OTV and a shelter to protect it. The dormant facility would not have the full compliment of propellant transfer and maintenance support equipment. The OTV at the storage facility would be transferred to the full-up maintenance facility in preparation for a mission.

SECTION 3

OTV MAINTENANCE/SERVICING FACILITY EVALUATION/RECOMMENDATION

It is inappropriate at this time, to select the final maintenance/facility approach for servicing an OTV at the Space Station. However, we must make some recommendations as to which approach(s) is viable so that the technologies to develop this capability can be identified. The text presents GDC's recommendations for viable approaches; the technologies to pursue these are presented in Section 5.

3.1 MAINTENANCE FACILITIES

Figure 3-1 presents the major pros and cons of the four alternative OTV servicing facilities concepts. We have tried to cover the range of major evaluation parameters but don't have the resources or time to perform the complete tradeoff analysis to make a recommendation as to the way to go. It would also be premature to do that at this time. From this evaluation we are trying to ascertain the most viable approaches to OTV maintenance/servicing so that we can identify the technologies to be pursued. The recommendation to meet this objective is summarized in a following table.

A parameter to be noted on this chart is the EVA activity and crew time. There is no EVA activity required on a normal turnaround for any option. There are different EVA times for periodic and unscheduled maintenance for different options. Over a year's operating, however, there is not a noticeable difference in the total crew time between the options. Table 3-1 lists this information.

Table 3-1. Manhour Comparison for 20 Mission Year

Predicted Task Requirements per Year	Shelter		Maint Module	
	Total	EVA	Total	EVA
20 turnarounds	1393:20	—	1526:40	—
4 fuel cell R/R	22:40	—	22:40	—
2 engine R/R	131:00	50:40	36:20	—
5 avionic R/R	27:30	—	16:40	—
1 aerobrake repair	26:20	9:10	26:20	9:10
2 tank R/R	116:30	41:00	116:30	41:00
Total man-hours per year	1717:20	100:50	1745:10	50:10
Percent EVA per year		5.87%		2.87%

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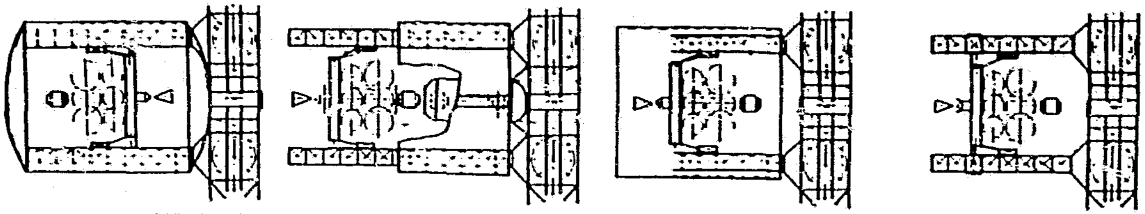

Space Station Impact	Full Pressurized Hangar	Pressurized Module/Shelter	Shelter	No Shelter
Facilities	• Complex hangar — construction/operation • Hangar pressure system	• Partial OTV access module • Module pressure system • Simple mobile shelter	• Simple mobile shelter • No pressure system	• No shelter • No pressure system
Life support system	• Large volume system • 14.7 psi O_2/N_2 with pump down & replenishment	• 1/10 hangar volume • 14.7 psi O_2/N_2 with pump down & replenishment • Extravelucular mobility units	• Extravehicular mobility unit(s)	• Extravehicular mobility unit(s)
OTV maintenance	• Shirtsleeve repair • Propellant servicing outside hangar	• Shirtsleeve & EVA repair • Propellant servicing in place	• Robotic & EVA repair • Propellant servicing in place	• Robotic & EVA repair • Propellant servicing in place
Safety	• Residual propellant hazard • Meteorite & radiation protection	• Residual propellant hazard • Meteorite & radiation protection	• Residual propellant safe • Meteorite & radiation protection	• Residual propellant safe • No environment protection
Facilities maintenance	• EVA repair • O_2/N_2 pump & supply system • Temperature regulation system • Door seals	• O_2/N_2 pump & supply system • Temperature regulator system • Door seals • Shelter mobility system	• Shelter mobility system	• No maintenance
Cost	• High cost	• Medium cost	• Lower cost	• Lowest cost

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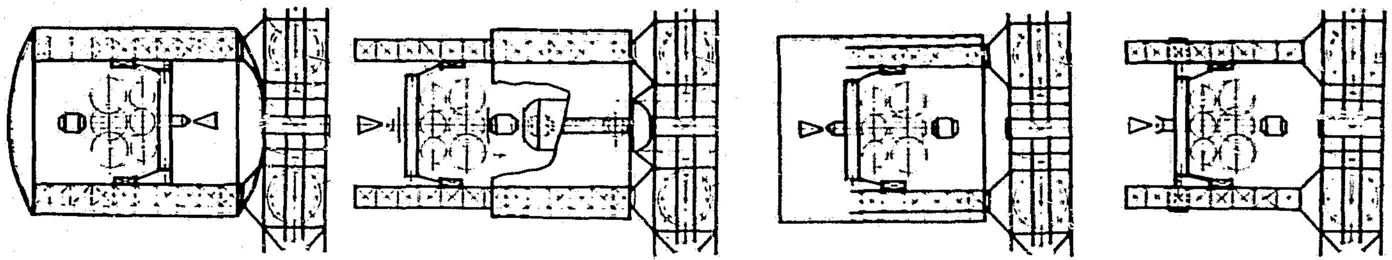
Figure 3-1. Maintenance Facility Evaluation (Sheet 1 of 2)



SPACE STATION IMPACT	FULL PRESSURIZED HANGAR	PRESSURIZED MODULE/SHELTER	SHELTER	No Shelter
EVA/crew time	• No EVA time (except for contingency) • Same robotic arm time • Essentially same crew time	• No EVA engine replace • EVA on tank module & aerobrake • Same robotic arm time • Essentially same crew time	• EVA on engine replace, tank module & aerobrake • Same robotic arm time • Essentially same crew time	• EVA on engine replace, tank module & aerobrake • Same robotic arm time • Essentially same crew time
Facility construction/ operation	• Construction very complex • Operate & seal very large door • Pump down large amount of gas	• Straightforward construction-standard SS module • Pump down system • Seal OTV bulkhead	• Straightforward construction & operation	• Simplest construction/operation
OTV impact	• Best debris protection – optimized performance	• Good debris protection • Slight performance degradation	• Good debris protection • Good performance	• No debris protection • Lower mass fraction • Less performance

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Figure 3-1. Maintenance Facility Evaluation (Sheet 2 of 2)

A nominal 20 mission year was formulated and summarized to provide a means for asessment of crew manhour requirements per year at the Space Station to support the OTV. This information gained allows for manhour comparisons between the shelter and maintenance module configurations. The chart also presents the expected amount of EVA involvement, which amounts to less than 6% of the total Level I maintenance effort.

Preventive maintenance changeouts were selected on the basis of fuel cell replacement every fifth mission and engine replacement after 10 missions. Unscheduled maintenance items and frequency of replacements were selected arbitrarily to show avionic, aerobrake, and tank module replacement activities throughout the year. Tank module changeout could also represent a configuration change for a manned mission.

The objective of GDC making a recommendation on OTV maintenance/servicing facility options at this time, in this study, is to ascertain the most viable approaches so that we can identify the technologies to be pursued.

Table 3-2, using the evaluation data previously displayed, summarizes GDC's recommendations and the rationale for them.

Table 3-2. OTV Maintenance Facility Selection to Identify Servicing Technologies to be Developed

No shelter	Not recommended because there is no protection for crewmen & OTV
Full Pressurized Hangar	Not recommended because of construction & operational complexity & cost. Other maintenance approaches are effective
✓ **Shelter**	Viable approach — most effective overall if OTV replacement modules have good access & simple remove & replace provisions for both EVA & robotic arm. EVA minimized to only complicated operations requiring man's presence
✓ **Shelter/ maintenance module—**	Viable approach — only advantage over shelter is IVA engine removal (possibly major engine power component module removal). Avionic packages proposed for robotic arm removal (doesn't neet shirt sleeve environment)
✓ **Selected**	

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We don't feel that a facility without a shelter is a viable approach because it does not offer protection for the OTV or the crew. A penalty for long term meteoroid protection on the OTV would reduce its performance and economic benefits.

GDC doesn't recommend a pressurized hangar because of the construction and operational complexity and cost. From the analyses, we feel the two recommended approaches are equally effective.

Both the shelter and shelter/maintenance module are viable approaches and a choice between them should not be made at this time. There isn't a lot of difference between them and essentially the same technologies are required to develop either capability.

3.2 PROPELLANT STORAGE/REFUELING FACILITIES

Table 3-3 lists some observations concerning the location of the propellant storage tanks.

Table 3-3. Propellant Transfer/Storage Facility Location Evaluation

- Phase I hazard analysis identified "foreign object collision puncturing a cryogen storage tank causing unbalanced reaction forces" as the major hazard to the station from propellant tanks
  - Recommended solutions
    - Shielding of tanks
    - Provide opposite reaction forces with RCS
    - Place tanks near center of gravity
- General Dynamics believes propellant storage tanks on the station can be adequately protected — not weight-critical
- May be a problem with center of gravity control & station attitude, which make propellant tanks on a separate platform more desirable

General Dynamics believes that, no matter where propellant tanks are placed, there is a requirement to transfer cryogenic propellant in zero-g

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In the Phase I study, we performed a hazard analysis to identify hazards and methods to eliminate them. The major hazard that was identified is shown in the table. Since the propellant storage tanks are not weight critical, GDC believes that they can be adequately protected with bumpers and shields.

The question of cg control is something that needs to be investigated. This is to be addressed by the Concept Development Group (CDG) at NASA Headquarters in the near future. Having a tethered or free flying depot has operational problems that must be solved.

However, GDC believes that no matter where propellant tanks are located, there is a requirement to transfer cryogenic propellants in zero-g. Therefore, this is a technology that should be developed.

SECTION 4

SPACE STATION FACILITIES/SUPPORT REQUIREMENTS FOR OTV SERVICING

This section identifies the OTV Maintenance/Servicing facilities for the maintenance module/shelter configuration, one of the viable approaches. It also identifies the Space Station requirements to support either the shelter or the maintenance module/shelter configuration.

4.1 OTV SERVICING FACILITIES

Table 4-1 identifies the major maintenance facility elements for the maintenance module configuration along with their predicted weights. The layout of these facilities is shown in Section 2.3.3 and the number of Shuttle launches to transport them to orbit is shown in Section 2.6.

You need to subtract 8630 pounds for the standard pressurized module structure and another 800 pounds for the OTV interface to get the weight of the equipment that is contained in the maintenance module, namely 3350 pounds. This equipment must be housed inside the Space Station for the shelter configuration.

4.2 SPACE STATION SUPPORT REQUIREMENTS

Table 4-2 lists the Space Station interface and support equipment that will be required to accommodate the space-based OTV facilities and operations. The direct Space Station interfaces occur at the maintenance facility truss structures, propellant modules, and refrigeration/control unit attach points. A maintenance module interface will also be required if that configuration is selected. The space-based OTV operations depend heavily on the translating station RMS, OMV, and payload handling equipment. The station RMS is used during the initial installation of this maintenance facility, during the assembly of the OTV at the Space Station, and other transfer operations. The OMV is an essential element for OTV launch deployment and capture operations.

The Space Station configuration should allow at least 60 ft^3 of space for OTV and maintenance facility control equiment, plus some space for attendant cooling hardware. A workshop facility of 120 ft^3 inside the Space Station is needed to provide for simple repair activities. This workshop area can be shared with other Space Station functions. An air lock for the EVA maintenance crew is required, along with translation equipment. A shirtsleeve access to a manned module will also be required. These volume and crew requirements are for the shelter configuration - a maintenance module configuration would provide these accommodations.

About 1200 watts of electrical power will be required for maintenance facility operations, with an additional 1500 watts dedicated for propellant conditioning and control.

The skills and levels for the crewmen are indicated.

Table 4-1. OTV Maintenance Facility for Maintenance Module/Shelter Configuration

Maintenance dock — 5,840 lb
- Main truss support structure
- OTV berthing interface, structure & translating and rotating mechanism & carriage
- Electrical interconnects between berthing interface, maintenance module & power source interface
- Fluid lines from quick disconnect panel to propellant storage control interface
- Support structures for shelter
- Rail/track system for shelter & berthing carriage
- Electrical interconnects between shelter interface, maintenance module & power source interface
- Handling device to provide EVA mobility & restraint, equipped with TV system & communications; RMS/robotic capability
- Electrical interconnects between handling device & maintenance dock interface

Maintenance shelter — 6,820 lb
- Main shelter structure
- Shelter to maintenance dock structure rail/track interface
- Shelter mobility control motors
- Lighting installation
- Electrical interconnects between lights & maintenance dock interface
- Exterior RMS support with rails/tracks
- RMS including TV, lights, end effector/tool adapter
- Electrical interconnects from RMS to maintenance dock interface
- Tool storage fixture for handling device/robotics & RMS
- Possible antenna installations

Propellant storage — 9,340 lb dry with 130,000 lb propellant (7,440 lb dry without refrigeration unit for 2nd tank)
- Main support structure
- Hydrogen storage tank
- Oxygen storage tank
- Control & interface unit, valves, controls, etc
- Fluid lines from tanks to control interface
- Refrigeration unit & plumbing
- Electrical interconnects between control unit, refrigeration unit, maintenance module & power source
- Radiators

Maintenance module/control station (standard module) — 12,780 lb
- Pressurized compartment
- Airlock for EVA operations (serves as observation module)
- Pressurized hatch & OTV interface
- General purpose computer system
- Dedicated control equipment including OTV docking, berthing & handling
- Communications & data links
- Observation & inspection equipment monitors (include TV, propellant sensors)
- Tools, maintenance & check out equipment & maintenance area
- Pressurized hatch for IVA regress/egress to manned mission module
- Spare parts storage volume to contain avionics ORUS, an engine, etc

Storage nacelles 2 each (1,440 lb included in shelter)
- Spare parts storage platform & holding fixtures with lights to contain 3 tank modules & a manned GEO mission module

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Table 4-2. Summary of Space Station Requirements to Support OTV Servicing

Support Requirements	Configuration	
	Shelter	Module
• Translating RMS & associated controls — RMS cherry picker adapter & adapter holding fixture	✓	✓
• Station interfaces for 2 truss structures, 2 propellant modules & 1 refrig/control unit — Mechanical attachments — Electrical interfaces — Fluid interfaces	✓	✓
• Maintenance module interfaces & utilities support		✓
• Electrical power — 600W maximum continuous +1,500W during reliquefaction & illumination (600W)	✓	✓
• Communication system — Ground & servicing installation & (radio frequency & hard line)	✓	✓
• Control station volume requirements 60 cu ft for equipment plus cooling system	✓	
• Pressurized workshop 120 cu ft (can be shared)	✓	
• OMV with control station & basing provisions	✓	✓
• Payload handling equipment	✓	✓
• (4) EVA suits with EMUs, including helmets with heads-up displays plus cleaning & storage facilities	✓	✓
• Airlock for EVA egress & ingress & translation system for EVA crew access to servicing installation	✓	
• Shirtsleeve ingress/egress to manned GEO crew module	✓	
• Crew skills: — 2 spacecraft systems professionals (skill 7, level 3) — 2 engineering technicians (skill 5, level 2)	✓	✓

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SECTION 5

TECHNOLOGY REQUIREMENTS

This section presents the results of Task 1 derived from the analyses that were performed. The tables identify the technologies that must be developed so that an OTV can be maintained and serviced on orbit. This data will be input to Task 4, Integrated Technology Development Plan. Task 4 will produce the development plan to mature the technology through ground, Shuttle sortie, and initial Space Station development tests.

Table 5-1 lists the five major SBOTV activities. The technologies for the on-orbit maintenance/servicing/mission build-up are identified in the following tables.

Table 5-1. Space-Based OTV Technology Requirements

Activation/checkout of operational OTV maintenance/servicing facilities

- Construction of shelter structure
- Deploying/handling/mating/interfacing/aligning servicing structure & equipment

Initial OTV delivery/assembly on-orbit

- No additional technology over maintenance/servicing

On-orbit maintenance/servicing

- See following charts

Mission build-up

- No additional technology over maintenance/servicing

Fleet operations/integrated logistics support (ILS)/rescue/retrieval

- No additional technology over maintenance/servicing

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The activation/checkout of operational OTV maintenance servicing facilities requires the development of the technologies shown in the table. The other major activities don't need additional technologies over the maintenance/servicing ones.

Tables 5-2 and following identify the technologies to perform the maintenance and servicing operations. The table lists the technologies for docking and berthing. Of particular interest is the proximity operation of the OTV around the Space Station. For this operation, the OMV and/or RMS will certainly be involved. An automated docking system needs to be developed.

Table 5-2. Space-Based OTV Technology Requirements for On-Orbit Maintenance/Servicing

OTV payload integration operations

Docking
- Stability & control system
- Monitor & control system
- Communications/radar
- Connecting up (OMV and/or RMS)
- Automated system/manual back up
- Space station proximity operations

Berthing
- Alignment sensors
- Contact sensors
- Coupling
- Repositioning/rotating

Maintenance
- Handling (concepts & equipment/EVA integration)
- Visual inspection (TV/EVA)
- Fault detection/isolation (down to R/R modular level)
- Remove & replace
  - Extravehicular Maneuvering Unit* (EMU)/EVA operations
  - Remote control arm operation
  - Automated operations
- Man-machine allocation
- Service Enclosure Operations
- System checkout

* See next chart for breakdown

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Table 5-2 lists also the technologies to be developed for the maintenance function and OTV payload integration operations. A further breakdown for the extravehicular maneuvering unit (EMU)/EVA operations is listed in Table 5-3.

Table 5-3. Space-Based OTV Technology Requirements for EMU/EVA Operations

Extravehicular Maneuvering Unit (EMU)
- No prebreathing/quick EVA preparation/quick-turnaroud
- Hard suit (higher operating pressure) with hard joints
- Rugged EMU — withstands sharp edge puncture, propellant contamination, radiation & extended wear
- Nonventing life support system
- Headsup display — real time access to data transfer from station or earth

EVA Operations
- Crewmen support/mobility/access
- R/R module attachment/release mechanisms
- Tools/support equipment/handling devices
- Procedures/timelines

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Table 5-4 identifies the technologies to be developed for zero-g cryogenic propellant handling. Because of the cost of delivering a pound of propellant to orbit, boiloff should be kept to a minimum and recovery of any boiloff should be accomplished through reliquefaction. To reduce the cost of delivering propellant to orbit, scavenging from the ET on Shuttle missions should be investigated. Also, using the ET as a tanker needs to be investigated to provide the resupply capacity required in the middle/late 90s.

Table 5-4. Space-Based OTV Technology Requirements for Zero-g Cryogenic Propellant Handling

Propellant transfer
- Leak free fluid couplings/quick disconnects
- Standard interfaces
- Acquisition devices
- Chilldown
- Gauging
- Leak detection

Long-term propellant storage
- Insulation/shielding
- Meteoroid protection
- Stratification, pressurization & mixing
- Venting

Reliquefaction
- Cycle selection
- Gas-free liquid expulsion

Propellant Resupply
- Scavenging
- Tanker

} Same technology as above

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The technologies identified in Table 5-4 are the most critical and have the highest priority for development as indicated in our Phase I final report. Work in these areas must be accelerated immediately to meet the IOC dates.

An integrated technology development plan for the technologies identified in this section will be developed as the next step in the study (Task 4) and will be put into a report at the conclusion of the task.

SECTION 6
SUMMARY

Table 6-1 summarizes the study to date and what will be accomplished in the future.

Phase I study has
- Driven out preliminary requirements for OTV technology development missions (TDM) on the initial station
- Defined the TDM hardware & initial space station interfaces & support

First half of Phase II study will
- Define OTV servicing technology requirements from analysis of operational OTV on the growth station
- Determine requirements on initial space station to support evolutionary space-based OTV development
- Determine technology development tests required on the initial space station from integrated development plan

Second half of Phase II study will, from results of above tasks, generate new
- TDM requirements along with concepts & operations
- Space station interface/support requirements for TDMs
- Precursor technology & TDM developement schedules & costs

OTV servicing requirements are a major driver for both the initial & growth station

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The Phase I study drove out preliminary requirements for OTV Technology Development Missions (TDM) on the initial station and defined the TDM hardware and station interfaces and support.

We have just completed defining the OTV servicing technology requirements from analysis of an operational OTV on the growth Station. The remaining two tasks in the first half of Phase II will be completed and reported on by the next interim review.

The second half of Phase II will accomplish the tasks shown. This will be the important data for the Space Station program.

It should be noted here that our study to date has pointed out that OTV servicing requirements are a major driver for both the initial and growth stations.

SECTION 7
REFERENCES

1. Space Tug Launch Site Service Interface Study, NAS 10-8031, General Dynamics Convair Division, GDCA-BNZ73-003, 1973.

2. Orbital Transfer Vehicle (OTV) Concept Definition Study, NAS 8-33533, General Dynamics Convair Division, GDC-ASP-80-012, 1981.

3. Manned Geosynchronous Mission Requirements and Systems Analysis Study, NAS 9-15779, Grumman Aerospace Corp.

4. A Study of Space Station Needs, Attributes and Architectural Concepts, NASW-3682 General Dynamics Convair Division, GDC-ASP-83-003, 1983.

APPENDIXES I — V

TASK ANALYSIS WORKSHEETS

The task analysis worksheets in the appendix back up the data presented in Section 2.4.

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LIST OF SYMBOLS

- $\boxed{}$ Total per functional task
- ( ) Total per task day
- [ ] Intermediate task times less than one day
- ◯ Shuttle activity not accountable to space station
- || Parallel operations
- I Inclusive operations designator
- Δ Momentary function

INITIAL MAINTENANCE FACILITY INSTALLATION — SHUTTLE MISSION 1
MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
	MAINTENANCE MODULE INSTALLATION		18:75						44:40	9:20
	— Day 1 —		(10:75)						(28:40)	(9:20)
	—Rendezvous and dock shuttle with station	Berthing facilities								
	—Bring system on line & review assembly plan	RMS & TV controls, computer system, communications link	1:00	4 2					4:00	
	—Grasp maintenance module with shuttle RMS	Shuttle RMS & controls, CCTV system	0:15	1		1 1			0:15	
	—Release maintenance module from shuttle	Shuttle automated release system	0:15	1		1 1			0:15	
	—Extend maintenance module to station and lock RMS	Shuttle RMS & control system	0:15	1		1 1			0:15	
	—Grasp maintenance module with station RMS	Station RMS & control system, CCTV system	0:15		1	1			0:30	

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INITIAL MAINTENANCE FACILITY INSTALLATION — SHUTTLE MISSION 1
MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
	—Release shuttle RMS and retract	Shuttle RMS & control system	0:10 ||	1		1 ||				
	—Translate mainte-nance module to station interface	Station RMS & control system	0:20		1	1			0:40	
	—Position maintenance module to mate with station		0:30		2				1:00	
	—Engage station structural inter-faces & latch	Module/station attachment interfaces	0:45		1	1			1:30	
	—Release & retract station RMS		0:10		1	1			0:20	
	—Perform pre-EVA tasks	Space suits, airlock	1:00 ||	2		1			3:15	
	—Grasp OTV mainte-nance facility accessories kit with shuttle RMS	Shuttle RMS & control system	0:15		1	1 1				
	—Release kit from shuttle	Shuttle automated release system	0:15			1 1				

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INITIAL MAINTENANCE FACILITY INSTALLATION — SHUTTLE MISSION 1
MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
	—Extend kit to station & lock RMS	Shuttle RMS & control system	0:15		1	1 1				
	—Grasp kit with station RMS	Station RMS & control system	0:15		1	1				
	—Release & retract shuttle RMS	Shuttle RMS & control system	0:10		1	1 1				
	—Translate kit to station	Station RMS & control system	0:20		1	1			0:40	
	—Resume shuttle mission activity		Δ							
	—Translate EVA crew to kit installation area	EVA translation device	0:15			1	2		0:45	0:30
	—Secure kit to station	Holding fixture or attach points	0:45			1	2		2:15	1:30
	—Release & retract station RMS	Station RMS & control system	0:10			1		2	0:30	0:20
	—Translate EVA crew to maintenance module	EVA translation device	0:15			1	2		0:45	0:30

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INITIAL MAINTENANCE FACILITY INSTALLATION — SHUTTLE MISSION 1
MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
	—Allow EVA ingress to module	Module airlock	0:15			1	2		0:45	0:30
	—Perform module to station interface tasks		1:00			1	2		3:00	2:00
	—Pressure check module system	Module controls & gauges or external instrumentation	0:30			1	2		1:30	1:00
	—Fully pressurize module & activate life support system	Module pressure system & ECSS	1:30			1	2		4:30	3:00
	—Perform post-EVA operations	EVA support equipment	1:00	2		1			3:00	
	— Day 2 —		(8:00)						(16:00)	
	● Perform module checkout		8:00	2					16:00	

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INITIAL MAINTENANCE FACILITY INSTALLATION — SHUTTLE MISSION 2
MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
	TRUSS STRUCTURE INSTALLATION		$\boxed{19:10}$						$\boxed{64:40}$	$\boxed{26:20}$
	— Day 1 —		(9:35)						(32:20)	(13:10)
	—Rendezvous & dock shuttle with station	Berthing facilities								
	—Bring system on line & review assembly plan	RMS & TV controls, computer system & communications link	1:00	4 2					4:00	
	—Perform pre-EVA operations	EVA support equipment	1:00	2		1			3:00	
	—Grasp 1st truss with shuttle RMS	Shuttle RMS & control system, CCTV system	0:15		1	1 1				
	—Release 1st truss from shuttle	Shuttle automated release system	0:15		1	1 1				
	—Position 1st truss for assembly & lock RMS	Shuttle RMS & control system	0:10		1	1 1				
	—Translate EVA crew to work area	EVA translation device	0:15			1	2		0:45	0:30

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INITIAL MAINTENANCE FACILITY INSTALLATION — SHUTTLE MISSION 2
MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
	—Erect collapsed portion of truss structure	Alignment equipment, structural extention & support equipment, & tools	1:30			1	2		4:30	3:00
	—Assemble berthing & cherry picker tracks on erected structure	Handling device, alignment equipment & tools	1:00			1	2		3:00	2:00
	—Inspect truss structure	TV system, structural	0:30		1		2		1:30	1:00
	—Translate EVA crew to safe area	EVA translation device	0:15			1	2		0:45	0:30
	—Grasp 1st structure with station RMS	Station RMS & control system	0:15		1	1		2	1:00	0:30
	—Release shuttle RMS & retract	Shuttle RMS & control system	0:10 ||		1	1 1 ||				
	—Translate truss to station		0:20		1	1		2	1:20	0:40
	—Position truss to mate with station		0:30		1	1		2	2:00	1:00

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INITIAL MAINTENANCE FACILITY INSTALLATION — SHUTTLE MISSION 2
MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
	—Engage station structural interfaces & latch	Automated engagement mechanism	0:45		2			2	3:00	1:30
	—Engage electrical & fluid interfaces & latch	Automated engagement mechanism	0:30 ||		1	1 ||			2:00	
	—Translate EVA crew to work area	EVA translation device	0:15			1	2			1:00
	—Inspect 1st truss installation	Alignment equipment & TV system	0:30		1		2		1:30	1:00
	—Translate EVA crew to station	EVA translation device	0:15			1	2		0:45	0:30
	—Perform post-EVA	EVA support equipment	1:00 ||	2		1 ||			3:15	
	—Deactivate all systems	Control panels	0:15		1	1				
	— Day 2 —		(9:35)						(32:20)	(13:10)
	● Repeat process to install 2nd truss structure									

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INITIAL MAINTENANCE FACILITY INSTALLATION — SHUTTLE MISSION 3
MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
	SHELTER INSTALLATION		$\boxed{108:25}$						$\boxed{326:15}$	$\boxed{98:40}$
	— Day 1 —		(8:15)						(23:20)	(5:20)
	—Rendezvous & dock shuttle with station	Berthing facilities								
	—Bring system on line & review assembly plan	RMS & TV controls, computer system & communications link	1:00	4 2					4:00	
	—Perform pre-EVA tasks	EVA support equipment	1:00 ||	2		1			3:15	
	*—Grasp 1st shelter panel with shuttle RMS	Shuttle RMS & control system	0:15		1	1 1				
	—Release panel from shuttle	Shuttle automated release system	0:15		1	1 1				
	—Extend panel to station & lock RMS	Shuttle RMS & control system	0:10		1	1 1				
	—Grasp panel with station RMS	Station RMS & control system	0:15		1	1				
	—Release & retract shuttle RMS	Shuttle RMS & control system	0:10 ||		1	1 1				

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INITIAL MAINTENANCE FACILITY INSTALLATION — SHUTTLE MISSION 3
MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
	—Translate panel to maintenance truss structure	Station RMS & control system	0:20		1	1			0:40	
	—Position panel for assembly & lock RMS		0:30		1	1			1:00	
	—Translate EVA crew to work area	EVA translation device	0:15			1	2		0:45	0:30
	—Attach panel to truss structure interface	Assembly fixture, latch mechanism & hand tools	0:30			1	2		1:30	1:00
	—Inspect panel installation	TV system	0:10		1		2		0:30	0:20
	—Translate EVA crew to safe area or station	EVA translation device	0:15			1	2		0:45	0:30
	—Release & retract station RMS	Station RMS & control system	0:10		1	1		2	0:40	0:20
	—Repeat shelter panel installation		3:05	Repeat from *					7:00	2:40

INITIAL MAINTENANCE FACILITY INSTALLATION — SHUTTLE MISSION 3
MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
	—Perform post-EVA tasks	EVA support equipment	1:00	2		1			3:15	
			||			||				
	—Deactivate all systems		0:15		1	1				
	— Day 2 thru 6 —		(41:15)						(116:40)	(26:40)
	● Repeat Day 1 to install remaining 10 panels									
	—Resume shuttle mission activity after day 6		Δ							
	— Day 7 —		(9:00)						(26:00)	(6:00)
	—Bring system on line & review inspection procedures	RMS & TV controls, computer system & communication link	1:00	4					4:00	
	—Perform pre-EVA tasks	EVA support equipment	1:00	2		1			3:00	
	—Inspect total shelter installation	TV & EVA translation device, alignment equip.	3:00			1	2		9:00	6:00

INITIAL MAINTENANCE FACILITY INSTALLATION — SHUTTLE MISSION 3
MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
	—Perform post-EVA tasks	EVA support equipment	1:00	2		1			10:00	
	—Perform shelter & berthing mobility checks	Facility control equipment, TV system	‖ 4:00		2					
	SHELTER STORAGE NACELLES									
	— Day 8 —		(11:20)						(33:15)	(12:10)
	—Bring system on line & review assembly plan	RMS & TV controls, computer system & communication link	1:00	4 2					4:00	
	—Perform pre-EVA	EVA support equipment	1:00	2		1			3:15	
	* —Grasp storage nacelle with shuttle RMS	Shuttle RMS & control system & TV system	‖ 0:15		1	1 1				
	—Release nacelle from shuttle	Shuttle automated release system	0:15		1	1 1				

INITIAL MAINTENANCE FACILITY INSTALLATION — SHUTTLE MISSION 3
MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
	—Extend nacelle to station	Shuttle RMS & control system	0:15		1	1 1				
	—Grasp nacelle with station RMS	Staion RMS & control system	0:15		1	1 1				
	—Release & retract shuttle RMS	Shuttle RMS & control system	0:10		1	1 1				
	—Translate nacelle to shelter interface	Station RMS & control	0:20		1	1			0:40	
	—Position nacelle for assembly on shelter & lock RMS	Interface guide pins	0:10		1	1			0:20	
	—Translate EVA crew to work area	EVA translation device	0:15			1	2		0:45	0:30
	—Unlatch nacelle packing restraints		0:10			1	2		0:30	0:20
	—Unfold nacelle	Captive extension mechanism	0:30			1	2		1:30	1:00
	—Secure nacelle in erected configuration	EVA hand tools	0:30			1	2		1:30	1:00

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INITIAL MAINTENANCE FACILITY INSTALLATION — SHUTTLE MISSION 3
MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
	—Attach nacelle to hinge plate on shelter	Latching devices	1:00			1	2		3:00	2:00
	—Inspect nacelle installation		0:30		1		2		1:30	1:00
	—Repeat process for 2nd nacelle		4:25		Repeat from *				11:00	5:50
	—Translate EVA crew to station	EVA translation device	0:15			1	2		0:45	0:30
	—Perform post-EVA tasks	EVA support equipment	1:00	2		1			4:00	
			||			||				
	—Perform nacelle operational tests	Facility control equipment	1:00		1	1				
	—Deactivate all systems	Control panels	0:15	1		1			0:30	

INITIAL MAINTENANCE FACILITY INSTALLATION — SHUTTLE MISSION 3
MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
	CHERRY PICKER INSTALLATION									
	— Day 9 —		(11:30)						(36:35)	(13:30)
	—Bring system on line & review assembly plan	RMS & TV controls, computer system, communication link	1:00	4					4:00	
	—Perform pre-EVA	EVA support equipment	1:00	2		1			3:30	
	* —Position RMS at maintenance facility accessories kit	Station RMS & control system, & TV system	0:15		1	1				
	—Grasp cherry picker with RMS		0:15		1	1				
	—Translate EVA crew to kit storage area	EVA translation device	0:15			1	2		0:45	0:30
	—Release cherry picker from kit holding fixture	Cherry picker holding fixture	0:15			1	2		0:45	0:30

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INITIAL MAINTENANCE FACILITY INSTALLATION — SHUTTLE MISSION 3
MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
	—Translate cherry picker to maintenance truss structure track system	Station RMS & control system	0:30		1	1		2	2:00	1:00
	—Position cherry picker for installation & lock RMS		0:10		1	1		2	0:40	0:20
	—Translate EVA crew to work area	EVA translation device	0:15			1	2		0:45	0:30
	—Install cherry picker on truss structure track		1:3υ			1	2		4:30	3:00
	—Release & retract RMS	Station RMS & control system	Δ							
	—Inspect cherry picker installation		0:20		1		2		1:00	0:40
	—Repeat installation process for 2nd cherry picker		3:45		Repeat	from	*		11:25	6:30

INITIAL MAINTENANCE FACILITY INSTALLATION — SHUTTLE MISSION 3
MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
	—Translate EVA crew to station	EVA translation device	0:15			1	2		0:45	0:30
	—Perform post-EVA tasks	EVA support	1:00	2		1			6:00	
			||			||				
	—Perform cherry picker operational checks		2:00		1	1				
	● Deactivate all systems		0:15		1	1			0:30	
	TV & LIGHTING INSTALLATION									
	— Day 10 —		(11:15)						(36:30)	(16:00)
	—Bring system on line and review assembly plan	RMS & TV controls, computer system, communication link	1:00	4					4:00	

INITIAL MAINTENANCE FACILITY INSTALLATION — SHUTTLE MISSION 3
MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
	—Perform pre-EVA tasks	EVA support equipment	1:00	2		1			3:30	
			||			||				
	—Position RMS at maintenance facility accessories kit	Station RMS & control system, TV system	0:15		1	1				
						||				
	—Grasp TV & lighting equipment		0:15		1	1				
	—Translate EVA crew to kit storage area	EVA translation device	0:15			1	2		0:45	0:30
	—Release equipment from kit	Holding fixtures	0:15			1	2		0:45	0:30
	—Translate EVA crew to work area (shelter)	EVA translation device	0:15			1	2		0:45	0:30
	—Translate equipment to shelter	Station RMS and control system	0:30		1	1		2	2:00	1:00
	—Install TV & lighting in shelter - 12 lights - 5 cameras	Cherry picker system	6:00			1	2		18:00	12:00

INITIAL MAINTENANCE FACILITY INSTALLATION — SHUTTLE MISSION 3
MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
	—Inspect TV & lighting installation	TV system, cherry picker	0:30		1		2		1:30	1:00
	—Transfer EVA crew to station	Cherry picker	0:15			1	2		0:45	0:30
	—Perform post-EVA tasks	EVA support equipment	1:00	2		1			4:00	
			||			||				
	—Perform TV & lighting operational checks	Facility TV & lighting controls	1:00		1	1				
	—Deactivate all systems		0:15		1	1			0:30	
	SHELTER RMS & CRANE INSTALLATION									
	— Day 11 —		(10:15)						(35:30)	(13:50)
	—Bring system on line & review assembly plan	RMS & TV controls, computer system, communication link	1:00	4					4:00	

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INITIAL MAINTENANCE FACILITY INSTALLATION — SHUTTLE MISSION 3
MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
	—Perform pre-EVA tasks	EVA support equipment	1:00 ||	2		1 ||			3:30	
	—Position RMS at maintenance facility accessories kit	Station RMS and control system	0:15		1	1 ||				
	—Grasp shelter RMS component with station RMS	Station RMS and control system	0:15		1	1				
	—Translate EVA crew to accessories kit area	EVA translation device	0:15			1	2		0:45	0:30
	—Release component from kit holding fixture	RMS holding fixture	0:15		1	1		2	1:00	0:30
	—Translate shelter RMS component to shelter	Station RMS	0:30		1	1		2	2:00	1:00
	—Position component for installation & lock station RMS	Station RMS	0:20		1	1			0:40	

INITIAL MAINTENANCE FACILITY INSTALLATION — SHUTTLE MISSION 3
MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
	—Translate EVA crew to work area	EVA translation device	0:15			1	2		0:45	0:30
	—Install shelter RMS on shelter track system	Alignment pins & EVA hand tools	1:00			1	2		3:00	2:00
	—Release & retract station RMS	Station RMS	0:10		1	1		2	0:40	0:20
	—Inspect shelter RMS installation	TV system	0:10		1		2		0:30	0:20
	—Translate EVA crew to accessories kit area	EVA translation device	0:15			1	2		0:45	0:30
	—Perform shelter RMS operational checks	Facility controls & TV system	0:30		2			2	2:00	1:00
	—Position station RMS at maintenance facility accessories kit	Station RMS and control system	0:15		1	1		2	1:00	0:30
	—Grasp scissor crane component with RMS		0:15		1	1		2	1:00	0:30

INITIAL MAINTENANCE FACILITY INSTALLATION — SHUTTLE MISSION 3
MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
	—Translate EVA crew to accessories kit area	EVA translation device	0:15			1	2		0:45	0:30
	—Release crane from kit holding fixture	Crane holding fixture	0:15			1	2		0:45	0:30
	—Transport crane to shelter	Station RMS and control system	0:30		1	1		2	2:00	1:00
	—Position crane for installation & lock RMS		0:15		1	1		2	1:00	0:30
	—Translate EVA crew to work area	Cherry picker system	0:15			1	2		0:45	0:30
	—Install crane on shelter	EVA hand tools	1:00			1	2		3:00	2:00
	—Release & retract RMS	Station RMS and control system	0:10		1	1		2	0:40	0:20
	—Inspect crane installation	TV system & translation device	0:10		1		2		0:30	0:20

INITIAL MAINTENANCE FACILITY INSTALLATION — SHUTTLE MISSION 3
MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
	—Translate EVA crew to station	EVA translation device	0:15			1	2		0:45	0:30
	—Perform post-EVA tasks	EVA support equipment	1:00 ||	2		1 ||			3:45	
	—Perform crane operational checks	Facility controls, TV system	0:30		1	1 ||				
	—Deactivate all systems	Control panels	0:15		1	1				
	REMOTE CONTROLLED ARM INSTALLATION									
	— Day 12 —		(5:50)						(20:25)	(5:40)
	—Bring system on line and review assembly plan	RMS & TV controls, computer system, communication link	1:00	4					4:00	
	—Perform pre-EVA tasks	EVA support equipment	1:00 ||	2		1 ||			3:30	

INITIAL MAINTENANCE FACILITY INSTALLATION — SHUTTLE MISSION 3
MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
	—Position RMS at maintenance facility accessories kit	Station RMS and control system	0:15		1	1				
	—Grasp remote control arm (RCA) with RMS		0:15		1	1				
	—Translate EVA crew to kit area	EVA translation device	0:15			1	2		0:45	0:30
	—Release RCA from kit holding fixture	RCA holding fixture	0:15			1	2		0:45	0:30
	—Translate RCA to truss structure track system	Station RMS and control system	0:15		1	1		2	1:00	0:30
	—Position RCA for installation & lock RMS		0:15		1	1		2	1:00	0:30
	—Translate EVA crew to work area	EVA translation device	0:15			1	2		0:45	0:30
	—Install RCA on track	Handling device & tools	1:00			1	2		3:00	2:00

INITIAL MAINTENANCE FACILITY INSTALLATION — SHUTTLE MISSION 3
MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
	—Release & retract RMS	Station RMS & control system	0:10		1	1		2	0:40	0:20
	—Inspect RCA installation	TV system translation device	0:10		1		2		0:30	0:20
	—Translate EVA crew to station	EVA translation device	0:15			1	2		0:45	0:30
	—Perform post-EVA tasks	EVA support equipment	1:00	2		1			3:45	
			||			||				
	—Perform preliminary RCA operational checks	Facility control system	0:30		1	1				
						||				
	—Deactivate all systems	Control panels	0:15		1	1				

INITIAL MAINTENANCE FACILITY INSTALLATION — SHUTTLE MISSION 4
MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
	PROPELLANT FACILITY & REFRIGERATION INSTALLATION		$\boxed{25:20}$						$\boxed{56:45}$	$\boxed{3:30}$
	— Day 1 —		(9:20)						(24:45)	(3:30)
	—Rendezvous & dock shuttle with station	Berthing								
	—Bring system on line and review assembly plan	Station RMS control system, TV control system, communication link	1:00	4 2					4:00	
	—Grasp propellant refrigeration & control unit with shuttle RMS	Shuttle RMS	0:15		1	1 1			0:15	
	—Release refrigeration & control unit from shuttle	Automated release mechanism	0:15		1	1 1			0:15	

INITIAL MAINTENANCE FACILITY INSTALLATION — SHUTTLE MISSION 4
MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
	—Extend refrigeration & control unit to station & lock RMS	Shuttle RMS & control system	0:15		1	1 1			0:15	
	—Grasp refrigeration & control unit with station RMS	Station RMS & control system	0:15		1	1			0:30	
	—Release & retract shuttle RMS	Shuttle RMS	Δ		1	1 1				
	—Resume shuttle mission activity		Δ							
	—Translate refrigeration & control unit to station interface	Station RMS and control system	0:20		1	1			0:40	
	—Perform pre-EVA tasks		1:00 ‖	2		1 ‖			4:00	
	—Position refrigeration & control unit to mate with station		0:30		1	1				

INITIAL MAINTENANCE FACILITY INSTALLATION — SHUTTLE MISSION 4
MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
	—Engage station interfaces & latch		0:30		1	1				
	—Release & retract station RMS	Station RMS and control system	0:10		1	1			0:20	
	—Translate EVA crew to work area	EVA translation device	0:15			1	2		0:45	0:30
	—Extend radiators		0:45			1	2		2:15	1:30
	—Inspect refrigeration & control unit installation		0:30		1		2		1:30	1:00
	—Transfer EVA crew to station	EVA translation device	0:15			1	2		0:45	0:30
	—Perform post-EVA tasks	EVA support equipment	1:00	2		1			3:15	
	—Grasp propellant module on shuttle with shuttle RMS	Shuttle RMS	0:15		1	1 1				
	—Release propellant module from shuttle		0:15		1	1 1				

INITIAL MAINTENANCE FACILITY INSTALLATION — SHUTTLE MISSION 4
MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
	—Extend propellant module to station		0:15		1	1 1				
	—Grasp propellant module with station RMS	Station RMS & control system	0:15		1	1 1				
	—Release & retract shuttle RMS	Shuttle RMS	0:10		1	1 1			0:10	
	—Translate propellant module to station interface	Station RMS & control system	0:20		1	1			0:40	
	—Position module to mate with station		0:20		1	1			0:40	
	—Engage module/ station interfaces & latch	Automatic latch system	0:20		1	1			0:40	
	—Release & retract station RMS	Station RMS and control system	0:10		1	1			0:20	
	—Inspect propellant module installation	TV system & controls	0:45		1	1			1:30	

INITIAL MAINTENANCE FACILITY INSTALLATION — SHUTTLE MISSION 4
MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
	—Activate propellant control system	Control system	0:30		1	1			1:00	
	—Perform extensive leak checks	Leak detectors	0:30		1	1			1:00	
	— Day 2 & 3 —									
	● Perform propellant facility operational checks		(16:00)		1	1			(32:00)	

INITIAL MAINTENANCE FACILITY INSTALLATION — SHUTTLE MISSION 5
MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
	PROPELLANT MODULE INSTALLATION		12:55						25:05	
	— Day 1 —		(4:55)	2					(9:05)	
	—Rendezvous & dock shuttle with station									
	—Bring system on line and review assembly plan	RMS & control system, TV & control system, communication link	1:00	2					2:00	
	—Grasp propellant module on shuttle with shuttle RMS	Shuttle RMS	0:15		1	1 1			0:15	
	—Release propellant module from shuttle		0:15		1	1 1			0:15	
	—Extend propellant module to station		0:15		1	1 1			0:15	
	—Grasp propellant module with station RMS	Station RMS & control system	0:15		1	1 1			0:30	

INITIAL MAINTENANCE FACILITY INSTALLATION — SHUTTLE MISSION 5
MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
	—Release & retract shuttle RMS	Shuttle RMS	Δ		1	1 1				
	—Translate propellant module to station interface	Station RMS & control system	0:20		1	1			0:40	
	—Position module to mate with station		0:20		1	1			0:40	
	—Engage module/ station interfaces & latch	Automatic latch	0:20		1	1			0:40	
	—Release & retract station RMS	Station RMS and control system	0:10		1	1			0:20	
	—Inspect propellant module installation	TV system & controls	0:45		1	1			1:30	
	—Activate propellant control system	Control system	0:30		1	1			1:00	
	—Perform extensive leak checks	Leak detectors	0:30		1	1			1:00	

INITIAL MAINTENANCE FACILITY INSTALLATION — SHUTTLE MISSION 5
MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
	— Day 2 —									
	• Perform propellant facility operational checks		(8:00)		1	1			(16:00)	

INITIAL OTV DELIVERY & ASSEMBLY
SHELTER/MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA DIRECT	IVA REMOTE	IVA SUPPORT	EVA ACTIVE	EVA STDBY	MANHOURS TOTAL	MANHOURS EVA
2.1.1 Unload tug from aircraft	INITIAL OTV DELIVERY AND ASSEMBLY		$\boxed{54:55}$						$\boxed{178:00}$	$\boxed{58:30}$
	— Day 1 —		(10:25)						(27:50)	(6:40)
2.1.1.1 Prepare aircraft for unloading	• Shuttle/station operations		[2:00]						[6:00]	
	—Open shuttle doors									
	—Rendezvous & dock with station	Docking facilities, OMV & RMS								
	—Bring all systems on line	RMS & control system, communication system, CCTV system, control panels, computer system, cherry picker	1:00		1	1			2:00	
	—Query computer & review assembly plan		1:00	4					4:00	

INITIAL OTV DELIVERY & ASSEMBLY
SHELTER/MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
2.1.1.2 Offload tug & pallet to cargo lift trailer	• Offload & position OTV core section for assembly		[0:50]						[1:35]	
	—Grasp OTV core section with station RMS	Station RMS & control system	0:15		1	1			0:30	
	—Initiate cradle support arm pryo release	Shuttle controls	0:05		1	1 1			0:05	
	—Position core section for assembly & lock RMS	Station RMS	0:30		1	1			1:00	
			||			||				
	—Activate & position shuttle RMS	Shuttle RMS	0:30		1	1 1				
	• Assemble tank trusses to core section		[5:35]						[16:15]	
	—Grasp 1st tank truss with shuttle RMS	Shuttle RMS	0:15		1	1 1			0:15	

INITIAL OTV DELIVERY & ASSEMBLY
SHELTER/MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
	—Position tank truss on core section	Shuttle RMS	0:30		1	1 1			3:00	
	—Perform pre-EVA tasks	EVA support equipment	1:00	2		1				
	—Translate EVA crew to work area	Cherry picker	0:15			1	2		0:45	0:30
	—Attach tank truss to core section	Latch devices	0:45			1	2		2:15	1:30
	—Move crew to safe area	Cherry picker	0:05			1	2		0:15	0:10
	—Release & reposition shuttle RMS	Shuttle RMS	0:15		1	1 1		2	0:45	0:30
	—Grasp 2nd tank truss with shuttle RMS	Shuttle RMS	0:15		1	1 1		2	0:45	0:30
	—Position tank truss on OTV core section	Shuttle RMS	0:30		1	1 1		2	1:30	1:00
	—Translate EVA crew to work area	Cherry picker	0:05			1	2		0:15	0:10

INITIAL OTV DELIVERY & ASSEMBLY
SHELTER/MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
	—Attach tank truss to core section	Latch devices	0:45			1	2		2:15	1:30
	—Release & stow shuttle RMS	Shuttle RMS	0:10		1	1 1		2	0:30	0:20
	—Translate EVA crew to station	Cherry picker	0:15			1	2		0:45	0:30
	—Post-EVA tasks	EVA support equipment	1:00	2		1			3:00	
2.1.1.3 Transfer tug & pallet to ground transport trailer	• Transfer core section to maintenance dock		$\boxed{2:00}$						$\boxed{4:00}$	
2.1.2 Move tug to TMF (PPF)	—Extend OTV core section with station RMS	Station RMS & control system	0:30		1	1			1:00	
	—Inspect berthing interfaces	TV system	0:15		1	1			0:30	
2.1.2.1 Transport to TMF (PPF)	—Position core section in dock berthing structure	Berthing structure, station RMS & control system	0:30		1	1			1:00	

INITIAL OTV DELIVERY & ASSEMBLY
SHELTER/MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
	—Latch core section with berthing mechanism	Berthing mechanism	0:05		1	1			0:10	
	—Release station RMS	Station RMS	0:05		1	1			0:10	
	—Rotate OTV core in maintenance dock	Rotation mechanism	0:15		1	1			0:30	
			||		||	||				
	—Reposition station RMS to shuttle	Station RMS & control system	0:15		1	1				
	—Clear & secure work site		0:10		1	1			0:20	
	—Deactivate & secure all systems	Facility control	0:10		1	1			0:20	
	— Day 2 —		(9:20)						(32:30)	(12:10)
	● Transfer and assemble 1st tank module to core section		$\boxed{9:20}$						$\boxed{32:30}$	$\boxed{12:10}$

INITIAL OTV DELIVERY & ASSEMBLY
SHELTER/MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
	—Query computer & review assembly plan	Computer system	1:00	4					4:00	
	—Perform pre-EVA tasks	EVA support equipment	1:00	2		1			4:00	
			||			||				
	—Bring all systems on line & activate RMS systems	Communication system, TV system, RMS & control systems, crane & cherry picker	1:00		1	1				
	—Grasp 1st tank module with station RMS	Station RMS & control system	0:15		1	1			0:30	
	—Translate EVA crew to shuttle bay	Cherry picker	0:15			1	2		0:45	0:30
	—Release tank from holding fixture	Holding fixture	0:20			1	2		1:00	0:40
	—Translate EVA crew to safe area at OTV worksite	Cherry picker	0:20			1	2		1:00	0:40

INITIAL OTV DELIVERY & ASSEMBLY
SHELTER/MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
	—Translate tank to crane with RMS	Station RMS, crane	0:30		1	1		2	2:00	1:00
	—Transfer tank to crane & move to OTV	Crane & handling adapter	0:30 ||		1	1 ||		2 ||	2:00	1:00
	—Stow RMS	Station RMS	0:15		1	1		2		
	—Translate EVA crew to work area	Cherry picker	0:05			1	2		0:15	0:10
	—Inspect OTV/tank interfaces on tank	TV system, cherry picker	0:10		1		2		0:30	0:20
	—Translate EVA crew to safe area	Cherry picker	0:05			1	2		0:15	0:10
	—Position tank for mounting	Crane & control system	0:30		1	1		2	2:00	1:00
	—Translate EVA crew to work area	Cherry picker	0:05			1	2		0:15	0:10
	—Attach tank/OTV interface	Guide pins, latch mechanisms, hand tools	1:00			1	2		3:00	2:00

INITIAL OTV DELIVERY & ASSEMBLY
SHELTER/MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
	—Perform tank/OTV interface inspection & checkout		1:00		1	1		2	4:00	2:00
	—Release crane & stow	Crane & control system	0:30		1		2		1:30	1:00
	—Clear & secure work area		0:30		1		2		1:30	1:00
	—Transfer EVA crew to station	Cherry picker	0:15			1	2		0:45	0:30
	—Perform post-EVA tasks	EVA support equipment	1:00	2		1			3:15	
	—Deactivate shelter facilities & all other pertinent systems	Facility control system	0:15		1	1				

INITIAL OTV DELIVERY & ASSEMBLY
SHELTER/MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
	— Day 3 —		(9:20)						(32:30)	(12:10)
	● Transfer and assemble 2nd tank module to core section		[9:20]						[32:30]	[12:10]
	—Query computer & review assembly plan	Computer system	1:00	4					4:00	
	—Perform pre-EVA tasks	EVA support equipment	1:00 ||	2		1 ||			4:00	
	—Bring all systems on line & activate RMS systems	Communication system, TV system, RMS & control systems, cherry picker, crane	1:00		1	1				
	—Grasp 2nd tank module with station RMS	Station RMS & control system	0:15		1	1			0:30	
	—Translate EVA crew to shuttle bay	Translation device	0:15			1	2		0:45	0:30
	—Release tank from holding fixture	Holding fixture & restraints	0:20			1	2		1:00	0:40

INITIAL OTV DELIVERY & ASSEMBLY
SHELTER/MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
	—Translate EVA crew to safe area at OTV worksite	Cherry picker	0:20			1	2		1:00	0:40
	—Translate tank to crane with RMS	Station RMS & crane control systems	0:30		1	1		2	2:00	1:00
	—Transfer tank to crane & move to OTV	Crane & control system	0:30		1	1		2	2:00	1:00
			||			||		||		
	—Stow RMS	Station RMS & control system	0:15		1	1		2		
	—Translate EVA crew to work area	Cherry picker	0:05			1	2		0:15	0:10
	—Inspect OTV/tank interfaces on tank	TV system, cherry picker	0:10		1		2		0:30	0:20
	—Translate EVA crew to safe area	Cherry picker	0:05			1	2		0:15	0:10

INITIAL OTV DELIVERY & ASSEMBLY
SHELTER/MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
	—Position tank for mounting	Crane & control system	0:30		1	1		2	2:00	1:00
	—Translate EVA crew to work area	Cherry picker	0:05			1	2		0:15	0:10
	—Attach tank/OTV interface	Guide pins & latch mechanisms	1:00			1	2		3:00	2:00
	—Perform tank/OTV interface inspection & checkout	TV system, cherry picker	1:00		1	1	2		4:00	2:00
	—Release crane & stow	Crane & control, handling adapter & holding fixture	0:30		1		2		1:30	1:00
	—Clear & secure work area		0:30		1		2		1:30	1:00
	—Transfer EVA crew to station	Cherry picker	0:15			1	2		0:45	0:30
	—Perform post-EVA tasks	EVA support equipment	1:00	2		1			3:15	
			||			||				
	—Deactivate shelter facilities & all other pertinent systems	Facility control system	0:15		1	1				

INITIAL OTV DELIVERY & ASSEMBLY
SHELTER/MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
	— Day 4 —		(8:30)						(28:00)	(8:20)
	● Offload and deploy aerobrake		[8:30]						[28:00]	[8:20]
	—Query computer & review assembly plan	Computer system	1:00	4					4:00	
	—Bring all systems on line	Facility controls, communications, computer system, TV	1:00		1	1			2:00	
	—Grasp aerobrake with station RMS	Station RMS	0:15		1	1			0:30	
	—Release aerobrake from shuttle	Shuttle release mechanism	0:05		1	1 1			0:05	
	—Perform pre-EVA tasks	EVA support equipment	1:00 ‖	2		1 ‖			4:00	
	—Translate aerobrake to maintenance dock & lock RMS	Station RMS	0:30		1	1				
	—Grasp aerobrake shelter RMS	Shelter RMS	0:10		1	1				

INITIAL OTV DELIVERY & ASSEMBLY
SHELTER/MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
	—Release & retract station RMS	Station RMS	0:15		1	1				
			||			||				
	—Translate aerobrake to aerobrake holding area	Shelter RMS	0:15		1	1				
	—Position aerobrake for assembly & lock RMS	Shelter RMS	0:05		1	1				
	—Translate EVA crew to aerobrake	Cherry picker	0:15			1	2		0:45	0:30
	—Remove stowing ribbon	Hand tools	0:15			1	2		0:45	0:30
	—Partially unfold radial beams (18)	Handling mechanism	0:15			1	2		0:45	0:30
	—Fully deploy & lock each radial beam (18)	Alignment tool, latch mechanism	1:00			1	2		3:00	2:00
	—Operate stretch tool mechanism & secure perimeter cable	Cable stretch tool	0:30			1	2		1:30	1:00

INITIAL OTV DELIVERY & ASSEMBLY
SHELTER/MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
	—Inspect aerobrake	TV system	1:00		1	1	2		4:00	2:00
	—Clear & secure work area		0:15		1	1	2		1:00	0:30
	—Translate EVA crew to safe area	Cherry picker	0:05			1	2		0:20	0:10
			||			||	||			
	—Position aerobrake for attachment to rail truss extender with RMS	Shelter RMS	0:05		1	1	2			
	—Translate EVA crew to aerobrake	Cherry picker	0:05			1	2		0:15	0:10
	—Attach rail truss extender to aerobrake	Truss extender & latches	0:15			1	2		0:45	0:30
	—Translate EVA crew to station	Cherry picker	0:15			1	2		0:45	0:30
	—Perform post-EVA tasks	EVA support equipment	1:00	2		1			3:35	
			||							
	—Release & retract shelter RMS	Shelter RMS	0:15		1	1				

INITIAL OTV DELIVERY & ASSEMBLY
SHELTER/MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
	—Extend rail truss with aerobrake	Truss extender	0:05		1	1				
	—Deactivate rail truss extender & secure	Facility control	Δ		1	1				
	—Deactivate all systems and secure	Facility control	0:15		1	1				
	— Day 5 —		(10:35)						(37:55)	(15:10)
	• Transfer and assemble engine module to OTV		$\boxed{10:35}$						$\boxed{37:55}$	$\boxed{15:10}$
	—Query computer to review assembly plan	Computer system	1:00	4					4:00	
	—Perform pre-EVA tasks	EVA support equipment	1:00 ‖	2		1 ‖			4:00	
	—Bring all systems on line & activate shelter facility	Facility controls	1:00		1	1				

INITIAL OTV DELIVERY & ASSEMBLY
SHELTER/MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
	—Translate EVA crew to shuttle bay	Translation device	0:15			1	2		1:00	0:30
			||			||				
	—Grasp engine with station RMS	Station RMS	0:15		1	1				
	—Release engine from holding fixture	Holding fixture	0:20			1	2		1:00	0:40
	—Translate EVA crew to OTV safe area	Translation device	0:20			1	2		2:00	1:00
			||			||				
	—Translate engine to crane	Station RMS	0:30		1	1				
	—Transfer engine to crane & move to OTV	Station RMS, crane	0:30		1	1		2	2:00	1:00
			||							
	—Stow RMS		0:15		1	1		2		
	—Translate EVA crew to work area	Cherry picker	0:05			1	2		0:15	0:10
	—Inspect engine interface	TV system.	0:10			1	2		0:30	0:20

INITIAL OTV DELIVERY & ASSEMBLY
SHELTER/MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
	—Translate crew to safe area	Cherry picker	0:05			1	2		0:15	0:10
	—Position engine for mounting	Crane & control system	0:30		1	1		2	2:00	1:00
	—Translate crew to work area	Cherry picker	0:05			1	2		0:15	0:10
	—Attach engine to OTV	Guide pins & latch mechanism	1:00			1	2		3:00	2:00
	—Inspect engine/OTV interface & perform checkout	TV system, facility checkout controls	1:30		1	1	2		6:00	3:00
	—Release crane and stow	Crane	0:30		1		2		1:30	1:00
	—Translate EVA crew to safe area	Cherry picker	0:05			1	2		0:15	0:10
	—Activate & retract rail truss extender	Truss extender	0:05		1	1		2	0:20	0:10

INITIAL OTV DELIVERY & ASSEMBLY
SHELTER/MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
	—Translate EVA crew to work area	Cherry picker	0:05			1	2		0:15	0:10
	—Attach aerobrake to OTV	OTV latch mechanism	0:30			1	2		1:30	1:00
	—Release rail truss extender from aerobrake	Truss extender latch mechanism	0:30			1	2		1:30	1:00
	—Deactivate rail truss extender	Truss extender controls	0:05		1	1		2	0:20	0:10
	—Clear & secure area		0:30		1	1	2		2:00	1:00
	—Transfer crew to station	Cherry picker	0:15			1	2		0:45	0:30
	—Perform post-EVA tasks	EVA support equipment	1:00	2		1			3:15	
			||			||				
	—Deactivate all systems	Facility control system	0:15		1	1				

INITIAL OTV DELIVERY & ASSEMBLY
SHELTER/MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
2.1.3 Perform new vehicle receiving inspection										
2.1.3.1 Position ground transport trailer for unloading										
2.1.3.2 Remove transport cover										
2.1.3.3 Attach horizontal lift bar										
2.1.3.4 Lift tug and pallet and place on floor										
2.1.3.5 Remove horizontal lift bar										

INITIAL OTV DELIVERY & ASSEMBLY
SHELTER/MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
2.1.3.6 Position work stands	— Day 6 —		(6:45)						(19:15)	(4:00)
2.1.3.7 Perform visual receiving inspection	• Inspect OTV assembly		$\boxed{4:00}$						$\boxed{13:45}$	$\boxed{4:00}$
	—Bring system on line	Facility control	0:15		1	1			3:15	
	—Perform pre-EVA tasks	EVA support equipment	1:00	2		1				
	—Translate EVA crew	Cherry picker	0:15			1	2		0:45	0:30
	—Perform visual inspection of OTV assembly	TV system, cherry picker	1:30		2		2		6:00	3:00
2.1.3.8 Remove work stands	—Translate EVA crew to station	Cherry picker	0:15			1	2		0:45	0:30
2.1.3.9 Attach pallet tractor	—Perform post-EVA tasks	EVA support equipment	1:00	2		1			3:00	

INITIAL OTV DELIVERY & ASSEMBLY
SHELTER/MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
2.1.3.10 Move to maintenance position	• Extend shelter to cover OTV	Control panel, computer system, CCTV system	0:15		1	1			0:30	
2.1.4 Perform new vehicle functional C/O	• Perform system operational testing	Control panel, computer system	2:00		2				4:00	
2.1.4.1 Attach horizontal lift bar										
2.1.4.2 Lift tug and place in MAT										
2.1.4.3 Remove horizontal lift bar										
2.1.4.4 Connect checkout GSE										
2.1.4.5 Accomplish avionics continuity and functional C/O										

INITIAL OTV DELIVERY & ASSEMBLY
SHELTER/MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
2.1.4.6 Accomplish propulsion sub-system system leak & functional C/O										
2.1.4.7 Secure from functional C/O & disconnect GSE										
2.1.5 Prepare for storage	Deactivate & stow all systems	Facility control system	$\boxed{0:30}$		1	1			1:00	
2.1.5.1 Attach horizontal lifting bar										
2.1.5.2 Lift tug from MAT work stand & place on handling pallet & secure										
2.1.5.3 Detach & remove lifting bar										
2.1.5.4 Install transport cover										

INITIAL OTV DELIVERY & ASSEMBLY
SHELTER/MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
2.1.5.5 Move tug to storage area										
2.1.5.6 Release pallet tractor and connect facility power										
2.1.6 Monitor tug in storage										
2.1.6.1 Activate monitor circuits										
2.1.6.2 Monitor and record sensor outputs										

NOTE: The summary times reflect the shelter configuration in the first entry and the maintenance module configuration in the second entry.

NORMAL TURNAROUND
SHELTER/MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
	— Day 1 —		(8:30/ 10:20)						(17:00/ 20:40)	
	● RENDEZVOUS AND CAPTURE OTV		$\boxed{3:00}$						$\boxed{6:00}$	
	—Bring all systems on line & review operations plan	Facility controls	1:00		1	1			2:00	
	—Rendezvous OTV within space station proximity	Station controls	Δ ||		1 ||	1 ||			0:40	
	—Activate OMV & RMS for OTV retrieval operations	OMV & RMS & control systems	Δ ||		1 ||	1 ||				
	—Deploy OMV	OMV & control system	0:20		1	1				
	—Rendezvous & dock OMV with OTV	Station controls	0:30		1	1			1:00	
	—Maneuver OTV within station RMS range	OMV & control system	0:45		1	1			1:30	

ORIGINAL PAGE IS OF POOR QUALITY

NORMAL TURNAROUND
SHELTER/MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
	—Grasp OTV with station RMS	Station RMS	0:15		1	1			0:30	
	—Release OMV from OTV	OMV & control system	Δ							
	—Position OTV near maintenance dock	Station RMS	0:10		1	1			0:20	
	● Berth OTV		$\boxed{1:00/ 2:50}$						$\boxed{2:00/ 5:40}$	
	—Inspect OTV berthing interface	TV system	0:10		1	1			0:20	
	—Position OTV in berthing structure	Station RMS, berthing structure	0:15		1	1			0:30	
	—Engage berthing structure & latch	Berthing mechanisms	0:05		1	1			0:10	
	—Release RMS from OTV & stow	Station RMS	0:15		1	1			0:30	
			||							
	—Rotate OTV to sheltered position & lock	Berthing rotation mechanisms	0:15		1	1				

ORIGINAL PAGE IS
OF POOR QUALITY

NOTE: The tasks on this page apply to maintenance module configuration only, for shelter configuration tasks proceed to page III-4 .

NORMAL TURNAROUND
MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
ORIGINAL PAGE IS OF POOR QUALITY	(Maintenance Module Only)									
	—Attach rail truss extender to aerobrake	Truss extender & controls	0:05		1	1			0:10	
	—Release aerobrake from OTV	OTV latch mechanism	Δ		1	1				
	—Extend rail truss with aerobrake	Truss extender	0:05		1	1			0:10	
	—Deactivate rail truss extender and secure	Truss extender	Δ		1	1				
	—Move OTV forward to engage pressure interfaces	Berthing carriage & controls, module/OTV interfaces	0:10		1	1			0:20	
	—Engage OTV collar & maintenance module interfaces		0:15		1	1			0:30	
	—Check pressure seal and pressurize	Pressurization system	1:15 ||		1	1			2:30	

NORMAL TURNAROUND.
SHELTER/MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
	—Extend shelter to cover OTV	Shelter controls	0:15		1	1			0:30	
3.1.1 Safe tug following landing	● Propellant transfer		$\boxed{1:45}$						$\boxed{3:30}$	
3.1.2 Purge main propellant tanks	—Verify interface integrity	Facility & OTV interface test equipment	0:15		1	1			0:30	
			||							
3.1.2.1 Position work stands	—Check electrical interface		0:15		1	1				
			||							
3.1.2.2 Attach purge & vent lines	—Check fluid interface	Leak detectors	0:15		1	1				
3.1.2.3 Purge LH_2 tank and verify	—Perform extensive propellant leak check	Leak detection system	0:30		1	1			1:00	
			||							
3.1.2.4 Purge LO_2 tank and verify	—Childown fluid transfer lines	Propellant facility controls	0:30		1	1				
3.1.2.5 Drain & inert ACPs	—Transfer propellant from OTV to station	Propellant storage and control system	1:00		1	1			2:00	
3.1.2.6 Remove purge & vent lines, Remove workstand										

NORMAL TURNAROUND
SHELTER/MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
3.3.1 Transfer to TMF										
3.3.1.1 Attach Orbiter to tug ground transport trailer at Orbiter MCF or at safing area										
3.3.1.2 Tow to TMF										
	● Inspect & planning		$\boxed{2:45}$						$\boxed{5:30}$	
1.1.1 Analyze data & prep preliminary maintenance action plan	—Query computer about fault status	Control panel, computer system	0:15 ||		1	1			0:30	
1.1.1.1 Review flight crew logs for required maintenance action items	—Record fault listing	Data entry panel	0:15		1	1				

NORMAL TURNAROUND
SHELTER/MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
1.1.1.2 Run and analyze flight recorder & telemetry data tapes										
1.1.1.3 Prepare preliminary maintenance action plans										
1.1.3 Position tug & workstands, demate tug/adapter										
1.1.4 Position & connect maint. test & service GSE										
1.1.4.1 Remove tug access doors and panels										
1.1.4.2 Install internal platforms in tug and position GSE for tug and adapter										
1.1.4.3 Connect GSE										

NORMAL TURNAROUND
SHELTER/MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
1.1.5 Visual inspection	—Perform visual inspection	CCTV system, control panel, inspection aids, RMS with CCTV and control system	2:00		2				4:00	
1.1.5.1 Inspect structural elements & thermal control	Thermal control									
1.1.5.2 Inspect tank supports and interior	Tank module				✓					
	—Tank support structure				✓					
	—Interconnect truss				✓					
	—Cantilever truss				✓					
	—Drag struts				✓					
	—Plumbing installation				✓					
	—Electrical installation				✓					

NORMAL TURNAROUND
SHELTER/MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
	—Core section interface				✓		✓			
	—Electrical					✓	✓			
	—Fuel					✓	✓			
	—Structure					✓	✓			
	Oxidizer tank				✓					
	—Thermal insulation									
	—Tank structure									
	—Acquisition system									
	—Plumbing interface									
	—Support structure I/F									
	—Transducer installation									

NORMAL TURNAROUND
SHELTER/MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
	Fuel tank				✓					
	—Tank structure									
	—Thermal insulation									
	—Acquisition system									
	—Plumbing interface									
	—Support structure I/F									
	—Transducer installation									
1.1.5.3 Inspect MLI & thrust structure	Core structure				✓					
	—Tank module interface				✓		✓			
	—Electrical					✓	✓			
	—Fuel lines					✓	✓			
	—Structure					✓	✓			

NORMAL TURNAROUND
SHELTER/MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
1.1.5.4 Inspect docking mechanism	—Berthing interface				✓					
	—Structure & latch system				✓					
	—Electrical				✓					
	—Fill & drain lines				✓					
	—Aerobrake interface structure				✓					
	—Engine interface				✓					
	- Structure					✓	✓			
	- Fuel lines					✓	✓			
	- Electrical					✓	✓			
	—Payload interface				✓					
	- Structure & latch				✓					
	- Electrical				✓					

NORMAL TURNAROUND
SHELTER/MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
	—Avionics module mounting				✓					
	- Electrical				✓					
	- Structure				✓					
	—Fuel cell mounting				✓					
	—Aft electrical unit installation				✓					
	<u>Aerobrake system</u>				✓					
	—Radial beams				✓					
	—Radial beam insulation				✓					
	—Ceramic cloth				✓					
	—Stowing ribbon				✓					
	—Perimeter cable				✓					
	—Stretch mechanism				✓					
	—Radial beam hinge & latch				✓					

NORMAL TURNAROUND
SHELTER/MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
	—Engine doors				✓					
	—Engine doors control				✓					
1.1.5.6 Inspect engine, fluid & pressure lines	Main engine				✓					
	—Core section interface					✓	✓			
	- Structure					✓	✓			
	- Fuel lines					✓	✓			
	- Electrical					✓	✓			
	—Turbopump & gear box				✓					
	—Controls & valve									
	—Plumbing & misc. hardware									
	—Ignition system									
	—Gimbal fuel & Ox lines									

NORMAL TURNAROUND
SHELTER/MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
	—Thrust chamber									
	—Nozzle									
	—Thrust vector control									
	- Actuators									
	- Servo controls									
	- Harness									
	—Attitude control system				✓					
	- Thruster modules									
	- Hydrazine tanks									
	- Feed & fill lines									
	- Heater blankets									
	- Plume impingement pads									
	- Harness									
	- Core section interface									

NORMAL TURNAROUND
SHELTER/MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
1.1.5.5 Inspect avionics & flight control units	Avionics				✓					
	Attitude update									
	- Star tracker (2)									
	- Sun sensor (2)									
	- Bus interface									
	- Fiber optic cabling									
	Guidance update									
	- Global positioning RCVR									
	- Processor									
	- Antennas									
	- RF switches									
	- RF cables									
	- Fiberoptic cabling									

NORMAL TURNAROUND
SHELTER/MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
	<u>Telemetry, tracking & control</u>									
	- S-band transponder (2)									
	- RF amplifier									
	- Pre mod processor (2)									
	- Antennas (2)									
	- Antenna select switch									
	- Hi/low power select switch									
	- RF cables									
	- Fiber optic cabling									
	<u>Rendezvous & docking</u>									
	- Rendezvous radar									

NORMAL TURNAROUND
SHELTER/MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
	- Low light level TV									
	- Laser radar									
	- LED latch sensor									
	- Signal processor									
	- Bus interface unit									
	- Antenna									
	- RF cable									
	- Fiber optic cabling									
	Guidance & control									
	- Guidance & control processor									
	- Bus interface unit									
	- Redundant inertial measurement unit									

NORMAL TURNAROUND
SHELTER/MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
	<u>Instrumentation & servo</u>				✓					
	- Signal conditioner									
	- Transducers									
	- Servo interface unit									
	- Data processor									
	- Bus interface unit									
	<u>Electrical power & control</u>									
1.1.5.7 Inspect fuel cells, functional C/O, R/R disconnect seals	- Fuel cells (2)				✓					
	- Batteries (2)				✓					
	- Power control unit				✓					
	- Aft elec. dist. unit				✓					

NORMAL TURNAROUND
SHELTER/MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
	- Bus interface units (2)				✓					
	- Electrical power harnesses				✓					
	- Fiber optic cabling				✓					
1.1.6 Perform post-flight fault isolation & scheduled C/O										
1.1.6.1 Perform scheduled checkout & fault isolate										
1.1.6.2 Perform leak check on LH_2 & LO_2 tanks and engine										
1.1.6.3 Inspect tug/orbiter interface										

NORMAL TURNAROUND
SHELTER/MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
1.1.7 Complete data analysis & final maintenance action plan	—Formulate integrated maintenance plan	Computer system	0:30	2					1:00	
	— Day 2 —									
	● R/R ACS module		(9:20) $\boxed{8:35}$						(18:40) $\boxed{17:10}$	
	—Query computer about maintenance plan	Computer system	0:10		1	1			0:20	
	—Bring all systems on line and activate shelter facilities	Facility control	0:15		1	1			0:30	
	—Verify ACS modules safe	Computer system caution warning	0:05		1	1			0:10	
	—Orient RCA in appropriate shelter quadrant	RCA & controls & ACS module adapter	0:10		1	1			0:20	
	—Select lighting for work area	Shelter lighting	Δ		1	1				
	—Operate TV for approach field of view	TV system	Δ		1	1				

C-2

NORMAL TURNAROUND
SHELTER/MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
	—Extend RCA to module	RCA & controls	0:05		1	1			0:10	
	—Operate TV for close-up	TV system	Δ							
	—Remove ACS module	RCA & controls	0:10		1	1			0:20	
	—Operate TV for regress	TV system	Δ		1	1				
	—Retract RCA & retrieve failed module	RCA & controls & module holding fixture	0:20		1	1			0:40	
	—Load RCA with replacement module	RCA & control	0:15		1	1			0:30	
	—Orient RCA in appropriate, shelter quadrant	RCA & control	0:10		1	1			0:20	
	—Operate TV for approach field of view	TV system	Δ		1	1				
	—Extend RCA with module	RCA & control	0:10		1	1			0:20	

NORMAL TURNAROUND
SHELTER/MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
	—Operate TV for close-up	TV system	Δ		1	1				
	—Install replacement module	RCA & control	0:10		1	1			0:20	
	—Verify interface integrity	OTV built-in test & facility control	0:05		1	1			0:10	
	—Perform checkout	OTV built-in test	0:10		1	1			0:20	
	—Operate TV for regress	TV system	Δ		1	1				
	—Retract RCA	RCA & control	0:10		1	1			0:20	
	—Deactivate shelter facilities and secure all systems	Facility control system	0:10		1	1			0:20	
	—Total time to R/R 3 additional ACS modules		6:00						12:00	

NORMAL TURNAROUND
SHELTER/MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
1.1.12 Perform scheduled maintenance - thermal control system										
1.2.1 Mate tug & tug-orbiter adapter										
1.2.1.1 Position adapter for mating										
1.2.1.2 Mate adapter and tug										
1.2.2 Perform docking mechanism functional C/O										
1.2.3 Perform post-maintenance C/O maintenance & refurb. sys. only	● Perform systems operational testing	Computer system, OTV built-in test and facility control	$\boxed{0:45}$		2				$\boxed{1:30}$	

NOTE: The tasks on this page apply to the shleter configuration only, for the maintenance module configuration, replace this page with pages III-25 & III-26.

NORMAL TURNAROUND
SHELTER

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA DIRECT	IVA REMOTE	IVA SUPPORT	EVA ACTIVE	EVA STDBY	MANHOURS TOTAL	MANHOURS EVA
	— Day 3 —		(5:15)						(10:30)	
2.1.7 Remove from storage	● Payload Integration		$\boxed{5:15}$						$\boxed{10:30}$	
2.1.7.1 Disconnect facility power from pallet	—Query computer & review plan	Computer system	1:00		1	1			2:00	
	—Bring system on line	Facility control	1:00		1	1			2:00	
2.1.7.2 Move tug to MAT area	—Retract shelter	Shelter controls	0:15		1	1			0:30	
2.1.7.3 Remove transport cover	—Rotate OTV	Berthing rotation mechanism	0:15		1	1			0:30	
2.1.7.4 Attach horizontal lift bar	—Activate & position RMS	Station RMS	0:15		1	1				
2.1.7.5 Lift tug and place in MAT work stand										
2.1.7.6 Remove horizontal lift bar										
2.1.8 Accomplish mission peculiar preparation										

NORMAL TURNAROUND
SHELTER/MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
2.1.8.1 Review mission planning and define mission peculiar requirements										
2.1.8.2 Accomplish mission peculiar preparation										
2.1.9 Perform final system & integrated systems test										
2.1.9.1 Test preparation and power on										
2.1.9.2 Accomplish complete subsystem system and integrated vehicle systems checkout including simulated countdown, launch and flight										
2.1.9.3 Secure from test and review data										

NORMAL TURNAROUND
MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
	— Day 3 —		(6:45)						(13:30)	
	• Payload integration		$\boxed{6:45}$						$\boxed{13:30}$	
	—Bring system on line line	Facility control system	1:00		1	1			2:00	
	—Query computer and review plan	Computer system	1:00	2					2:00	
	—Alert personnel to exit OTV area in maintenance module & seal	Caution & warning system module/OTV interface	Δ							
	—Seal off OTV maintenance area	Module/OTV pressure seal	0:20		1	1			0:40	
	—Decrease pressure in maintenance module OTV area	Pressurization system	0:30		1	1			1:00	
	—Disengage OTV collar & maintenance module interface	Module/OTV interface	0:15		1	1			1:00	
	—Withdraw OTV from maintenance module	Berthing carriage & control	0:10		1	1			0:20	
	—Position OTV for aerobrake attachment		0:05		1	1			0:10	

NORMAL TURNAROUND
MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
	—Retract rail truss with aerobrake	Truss extender & controls	0:05		1	1			0:10	
	—Latch aerobrake/OTV support truss to OTV	OTV latch mechanism	0:05		1	1			0:10	
	—Release rail truss extender from aerobrake & stow	Truss extender latch mechanism	Δ		1	1				
	—Retract shelter	Shelter & controls	0:15		1	1			0:30	
	—Rotate OTV to receive payload	Berthing rotation mechanism	0:15		1	1			0:30	
			||							
	—Activate & position RMS	RMS system	0:15		1	1				

NORMAL TURNAROUND
SHELTER/MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
2.1.12 Secure from maintenance and systems test										
2.1.12.1 Return all systems to inactive status										
2.1.12.2 Disconnect maintenance, test & checkout GSE										
2.1.12.3 Remove internal platforms and access ladders										
2.1.12.4 Reinstall/close all access doors										
2.1.12.5 Attach horizontal lifting bar										
2.1.12.6 Lift tug and place on handling pallet										

NORMAL TURNAROUND
SHELTER/MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
2.1.12.7 Release horizontal lifting bar										
2.1.12.8 Position mate/demate work stand										
2.2.4 Install COMMSEC equipment										
2.2.5 Mate tug & spacecraft										
2.2.5.1 Attach horizontal lift bar to handling pallet	—Grasp payload	Station RMS	0:15		1	1			0:30	
	—Release payload from holding fixture	Payload holding fixture	0:10		1	1			0:20	
2.2.5.2 Lift tug and pallet and place on ground transport trailer										

NORMAL TURNAROUND
SHELTER/MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
2.2.5.3 Remove horizontal lift bar										
2.2.5.4 Position mating work stand	—Transfer payload to OTV	Station RMS	0:30		1	1			1:00	
2.2.5.5 Hoist S/C to mating position	—Position P/L to mate with OTV	Station RMS	0:45		1	1			1:30	
2.2.5.6 Mechanically join tug and S/C	—Activate OTV pull down & lock mechanism	Station controls & OTV mechanisms	0:05		1	1			0:10	
2.2.5.7 Connect fluid and electrical interface panels										
2.2.5.8 Remove S/C handling sling										
2.2.6 Verify tug-spacecraft interfaces	—Verify OTV/payload interface	Computer system, control panel	0:15		1	1			0:30	

NORMAL TURNAROUND
SHELTER/MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
2.2.7 Perform integrated systems test (tug/S/C)	—Perform OTV/payload integration test	Computer system, control panel	0:30		1	1			1:00	
2.2.8 Mate tug & velocity package	—Deactivate all systems	Facility control system	0:15		1	1			0:30	
	— Day 4 —		(11:45)						(23:30)	
	● Transfer propellant from station to OTV		$\boxed{6:00}$						$\boxed{12:00}$	
	—Chill down transfer lines	Control panel, computer system	1:00		1	1			2:00	
	—Chill down OTV tanks		1:00		1	1			2:00	
	—Transfer propellant	Propellant storage & transfer system	4:00		1	1			8:00	
	—Perform leak check	Leak detection system	Contin-uous							

NORMAL TURNAROUND
SHELTER/MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
	● Prelaunch		$\boxed{4:00}$						$\boxed{8:00}$	
2.4.5 Conduct terminal countdown	—Perform prelaunch operations/ countdown	Communication & data link system, control panel, computer system	4:00 (ISPM)		2				8:00	
	- Grasp with RMS	RMS system								
	- Dock OMV to OTV	OMV system								
	● Launch		$\boxed{1:45}$ (ISPM)						$\boxed{3:30}$	
	—Launch phase 1	RMS system, automatic release mechanism, computer system, TV system, OMV system	Δ		2					
	—Deploy	OMV system	0:45		2				1:30	
	—Retrieve OMV	OMV system	0:45 ||		2					
	—Post launch - space station secure		1:00		2				2:00	

REMOVE & REPLACE FUEL CELL — PERIODIC
SHELTER/MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
1.1.10 Perform scheduled maintenance - avionics system										
1.1.10.1 Checkout & calibrate instrumentation pickups and potentiometers										
1.1.10.2 Checkout thermocouple and wiring										
1.1.10.3 Install data recorder tapes										
1.1.10.4 Remove and replace TV lights										

REMOVE & REPLACE FUEL CELL — PERIODIC
SHELTER/MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
1.1.10.5 Install and verify fuel cell power unit (every 6th flight)	● R/R fuel cell/ battery		$\boxed{2:50}$						$\boxed{5:40}$	
	—Query computer about maintenance plan	Computer system	0:10		1	1			0:20	
	—Bring all systems on line and activate shelter facility	Facility controls	0:15		1	1			0:30	
	—Verify fuel cell/ battery safe	Control panel	Δ		1	1				
	—Orient RCA in appropriate shelter quadrant	RCA & control system	0:10		1	1			0:20	
	—Select lighting for work area	Shelter lighting	Δ		1	1				
	—Operate TV for approach field of view	TV system	Δ		1	1				
	—Extend RCA to fuel cell/battery	RCA & control system	0:05		1	1			0:10	

REMOVE & REPLACE FUEL CELL — PERIODIC
SHELTER/MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
	—Operate TV for close-up	TV system	Δ		1	1				
	—Remove fuel cell/ battery	Control panel & RCA	0:20		1	1			0:40	
	—Operate TV for regress	TV system	Δ		1	1				
	—Retract RCA & retrieve failed fuel cell/battery	RCA & control system	0:20		1	1			0:40	
	—Load RCA with replacement fuel cell/battery	RCA & control system, fuel cell holding fixture	0:15		1	1			0:30	
	—Orient RCA in appropriate shelter quadrant	RCA & control system	0:10		1	1			0:20	
	—Operate TV for approach field of view	TV system	Δ		1	1				
	—Extend RCA with fuel cell/battery	RCA & control system	0:05		1	1			0:10	

REMOVE & REPLACE FUEL CELL — PERIODIC
SHELTER/MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
	—Operate TV for close-up	TV system	Δ		1	1				
	—Install replacement fuel cell/battery	RCA & control system	0:20		1	1			0:40	
	—Verify interface integrity	OTV built-in tests & control panel	0:05		1	1			0:10	
	—Perform checkout	OTV built-in test & control panel	0:10		1	1			0:20	
	—Operate TV for regress	TV system	Δ		1	1				
	—Retract RCA & stow	RCA & control system	0:10		1	1			0:20	
	—Deactivate shelter facilities & secure all systems.	Facilities control system	0:15		1	1			0:30	

REMOVE & REPLACE ENGINE — PERIODIC
SHELTER

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
1.1.11 Accomplish scheduled maintenance propulsion system Centaur Procedure HPS 1-00347	• R/R engine — Day 1 —		$\boxed{18:40}$ (8:15)						$\boxed{65:30}$ (28:15)	$\boxed{25:20}$ (10:30)
—Review procedures	—Query computer & review maintenance plan	Computer system	1:00	4					4:00	
—Obtain planning paper	—Bring all systems on line & position equipment	Computer system, facility control panels	1:00 ||		1 ||	1			4:00	
—Pick up handling tool with overhead crane	—Perform pre-EVA tasks	EMU, airlock system, EVA tools	1:00	2	1					
—Position crane over engine	—Translate EVA crew to work area	Cherry picker system, lighting, CCTV, communications	0:15			1	2		0:45	0:30
	—Attach rail truss extender to aerobrakes	Rail truss extender	0:15			1	2		0:45	0:30

REMOVE & REPLACE ENGINE — PERIODIC
SHELTER

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
	—Release aerobrake from OTV	EVA type latches	0:30			1	2		1:30	1:00
—Remove plumbing & electrical wiring	—Translate EVA crew to safe area	Cherry picker	0:05			1	2		0:15	0:10
—Drain lines & reduce pressure to zero	—Extend rail truss with aerobrake	Truss extender	0:05		1	1		2	0:20	0:10
—Disconnect 12 plugs & tie back	—Translate EVA crew to engine work area	Cherry picker	0:05			1	2		0:15	0:10
—Install handling tool on engine	—Attach crane to engine	Scissor crane, handling adapter	0:30		1		2		1:30	1:00
—Support engine weight with crane										
—Remove 2 actuators	—Release engine/OTV interface	EVA quick disconnect latches	1:00			1	2		3:00	2:00
—Remove 4 engine mounting bolts	—Translate EVA crew to safe area		0:05			1	2		0:15	0:10
—Verify engine free for hoisting										

REMOVE & REPLACE ENGINE — PERIODIC
SHELTER

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
—Raise engine & place on trailer	—Remove engine & transfer to RMS	Shelter RMS	0:30		1	1			2:00	1:00
			||			||				
	—Translate EVA crew to work area & inspect OTV interface	Cherry picker	0:30			1	2			
	—Translate engine to holding fixture	Shelter RMS	0:20		1	1			1:20	0:40
			||							
	—Translate EVA crew to engine storage area	Cherry picker	0:20				2			
	—Position engine in holding fixture	Engine holding fixture	0:20		1	1		2	1:20	0:40
—Secure engine to trailer	—Secure engine in holding fixture & release RMS		0:30			1	2		1:30	1:00
—Install support to LO_2 & fuel lines	—Clean & secure work area		0:30		1		2		1:30	1:00

REMOVE & REPLACE ENGINE — PERIODIC
SHELTER

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
—Cover gimbal block & tie	—Translate EVA crew to station	Cherry picker	0:15			1	2		0:45	0:30
	—Perform post-EVA tasks	EVA support equipment	1:00	2		1			3:15	
			||			||				
	—Deactivate & secure all systems	Facility control system	0:15		1	1				
	— Day 2 —		(10:25)						(37:15)	(14:50)
	—Query computer to review maintenance plan	Computer system	1:00	4					4:00	
	—Perform pre-EVA tasks	EVA support equipment	1:00	2		1			4:00	
			||			||				
	—Bring all systems on line & activate shelter facility	Facility controls	1:00		1	1				
	—Translate EVA crew to work area	Cherry picker	0:15			1	2		1:00	0:30
			||			||				
	—Grasp replacement engine with RMS	Shelter RMS	0:15		1	1				

REMOVE & REPLACE ENGINE — PERIODIC
SHELTER

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
	—Release engine from holding fixture	Holding fixture and latch mechanism	0:20			1	2		1:00	0:40
	—Translate EVA crew to OTV safe area	Cherry picker	0:20			1	2		1:20	0:40
			||			||				
	—Translate engine to crane	Shelter RMS	0:20		1	1				
	—Transfer replacement engine to crane & move to OTV	Shelter RMS & crane	0:30		1	1		2	2:00	1:00
			||							
	—Stow RMS	Shelter RMS	0:15		1	1		2		
	—Translate EVA crew to work area	Cherry picker	0:05			1	2		0:15	0:10
	—Inspect engine interface	TV system	0:10		1		2		0:30	0:20
	—Translate crew to safe area	Cherry picker	0:05			1	2		0:15	0:10
	—Position engine for mounting	Crane	0:30		1	1		2	2:00	1:00

REMOVE & REPLACE ENGINE — PERIODIC
SHELTER

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
	—Translate crew to work area	Cherry picker	0:05			1	2		0:15	0:10
	—Attach engine to OTV	OTV latch mechanisms & facility control	1:00			1	2		3:00	2:00
	—Inspect engine/OTV interface & perform checkout	TV system, OTV built-in tests & facility control	1:30		1	1	2		6:00	3:00
	—Release crane and stow	Crane	0:30		1		2		1:30	1:00
	—Translate EVA crew to safe area	Cherry picker	0:05			1	2		0:15	0:10
	—Activate & retract rail truss extender	Truss extender & control	0:05		1	1		2	0:20	0:10
	—Translate EVA crew to work area	Cherry picker	0:05			1	2		0:15	0:10
	—Attach aerobrake to OTV	OTV latch mechanism	0:30			1	2		1:30	1:00

REMOVE & REPLACE ENGINE — PERIODIC
SHELTER

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
	—Release rail truss extender from aerobrake	Truss extender & control	0:30			1	2		1:30	1:00
	—Deactivate rail truss extender	Facility controls	0:05		1	1		2	0:20	0:10
	—Clear & secure area		0:30		1	1	2		2:00	1:00
	—Transfer crew to station	Cherry picker	0:15			1	2		0:45	0:30
	—Perform post-EVA tasks	EVA support equipment	1:00	2		1			3:15	
			||			||				
	—Deactivate all systems	Facility control systems	0:15		1	1				

REMOVE & REPLACE ENGINE — PERIODIC
MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
1.1.11 Accomplish scheduled maintenance propulsion system	• Scheduled maintenance									
	• R/R engine		$\boxed{9:05}$						$\boxed{18:10}$	
	—Bring all systems on line	Computer system, control panels	0:15	2					0:30	
Centaur Procedure HPS 1-00347	—Query computer & review maintenance plan	Computer system	0:30	2					1:00	
—Review procedures	—Determine that OTV engine is free of contaminants	Remote propellant sensors	0:15		1	1			0:30	
—Obtain planning paper	—Alert personnel to exit OTV interface area	Caution & warning system, maintenance module airlock	Δ	2						
—Pick up handling tool with overhead crane	—Withdraw OTV from maintenance module	Pressurization system, berthing carriage & controls	1:15		1	1			2:30	
—Position crane over engine			||							
	—Retract shelter	Shelter mobility & controls	0:15		1	1				

REMOVE & REPLACE ENGINE — PERIODIC
MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
—Remove plumbing & electrical wiring	—Rotate OTV 180 deg & orient engine to maintenance module	Rotational berthing mechanism & control	0:20		1	1			0:40	
—Drain lines & reduce pressure to zero	—Move OTV towards maintenance module	Berthing carriage & controls	0:10 ||		1	1			0:30	
—Disconnect 12 plugs & tie back	—Extend shelter	Facility controls	0:15		1	1				
—Install handling tool on engine	—Engage OTV aft collar & maintenance module interface	Pressurized interface maintenance module	0:15		1	1			0:30	
—Support engine weight with crane	—Check pressure seal & pressurize	Pressurization system	1:15		1	1			2:30	
—Remove 2 actuators										
—Remove 4 engine mounting bolts	—Attach crane to engine	Scissor crane, handling adapter	0:15	2					0:30	
—Verify engine free for hoisting	—Disengage engine/ OTV interface	Tools, quick disconnects	0:30	2					1:00	
—Raise engine & place on trailer	—Remove engine from OTV & move to holding fixture		0:15	2					0:30	

REMOVE & REPLACE ENGINE — PERIODIC
MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
—Secure engine to trailer	—Place engine in holding fixture & secure	Engine holding fixture	0:15	2					0:30	
—Install support to LO_2 & fuel lines	—Inspect OTV engine interface		0:10	2					0:20	
—Cover gimbal block & tie										
	—Attach crane to replacement engine	Scissor crane, handling adapter	0:05	2					0:10	
	—Release replacement engine from holding fixture	Engine holding fixture	0:05	2					0:10	
	—Move engine to OTV & position	Scissor crane	0:15	2					0:30	
	—Engage engine/OTV interface & secure	Guide pins, latch mechanism	0:30	2					1:00	
	—Release crane & stow		0:10	1		1			0:20	
	—Perform engine installation inspection tasks		0:15	2					0:30	

REMOVE & REPLACE ENGINE — PERIODIC
MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
	—Perform engine checkout	OTV built-in test facility controls	0:10	2					0:20	
	—Clear & secure work area		0:15	2					0:30	
	—Alert personnel to exit OTV interface area	Caution & warning system	Δ	2						
	—Seal off OTV interface area	Module/OTV pressure interface	0:20		1	1			0:40	
	—Decrease pressure in OTV interface area	Pressurization system	0:30		1	1			1:00	
	—Disengage OTV aft collar & maintenance module & interface	Modules/OTV interface	0:15		1	1			0:30	
	—Withdraw OTV from maintenance module	Berthing carriage & controls	0:10		1	1			0:20	
	—Enter complete job in maintenance plan	Computer system	0:05		1	1			0:10	
	—Deactivate all systems	Facility controls	0:15		1	1			0:30	

REMOVE & REPLACE AVIONICS MODULE — UNSCHEDULED
SHELTER

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
1.1.8 Perform unscheduled maintenance & refurbish all systems ——— Detail not available	• Perform unscheduled maintenance • R/R avionics module		$\boxed{2:45}$						$\boxed{5:30}$	
	—Bring all systems on line	Computer system, maintenance facility & controls	0:15		1	1			0:30	
	—Query computer & review maintenance plan		0:15		1	1			0:30	
	—Orient RCA in appropriate shelter quadrant	RCA & control panel, CCTV, lighting	0:10		1	1			0:20	
	—Extend RCA to module		0:05		1	1			0:10	
	—Remove insulation panel	RCA adapter	0:10		1	1			0:20	

REMOVE & REPLACE AVIONICS MODULE — UNSCHEDULED
SHELTER

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
	—Remove avionics module		0:10		1	1			0:20	
	—Inspect OTV module interface	CCTV	0:05		2				0:10	
	—Translate RCA & stow failed module	Module holding fixture	0:15		1	1			0:30	
	—Load RCA with replacement module		0:05		1	1			0:10	
	—Orient RCA in appropriate shelter quadrant		0:10		1	1			0:20	
	—Extend RCA with module		0:10		1	1			0:20	
	—Install replacement module		0:15		1	1			0:30	
	—Replace insulation panel		0:10		1	1			0:20	
	—Perform checkout		0:10		1	1			0:20	

REMOVE & REPLACE AVIONICS MODULE — UNSCHEDULED
SHELTER

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
	—Retract & stow RCA		0.10		1	1			0:20	
	—Enter completed task in maintenance plan		0:05		1	1			0:10	
	—Deactivate shelter facilities		0:05		1	1			0:10	

REMOVE & REPLACE AVIONICS MODULE — UNSCHEDULED MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
1.1.8 Perform unscheduled maintenance & refurbish all systems	• Perform unscheduled maintenance • R/R avionics module		1:40						3:20	
Detail not available	—Bring all systems on line	Computer system	0:15	2					0:30	
	—Query computer & review maintenance plan		0:15	2					0:30	
	—Obtain tools from tools storage kit	Tool kit	0:30	1		1			0:06	
	—Locate avionics module on OTV		0:02	1		1			0:04	
	—Remove insulation panel	Quick disconnects	0:05	2					0:10	
	—Insert extraction tool & release module	Extraction tool	0:01	2					0:02	

REMOVE & REPLACE AVIONICS MODULE — UNSCHEDULED
MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
	—Remove avionics module		0:02	2					0:04	
	—Place module in repair storage rack	Storage fixtures	0:05	1		1			0:10	
	—Obtain new module from spares rack	Spares holding fixtures	0:05	1		1			0:10	
	—Insert new module in OTV		0:10	2					0:20	
	—Latch & secure module in OTV		0:03	2					0:06	
	—Inspect avionics installation		0:05	2					0:10	
	—Replace insulation panel		0:05	2					0:10	
	—Inspect insulation replacement		0:02	2					0:04	
	—Clear area & return tools to kit		0:05	1		1			0:10	

REMOVE & REPLACE AVIONICS MODULE — UNSCHEDULED
MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
	—Perform operational test		0.10		2				0:20	
	—Enter completed task in maintenance plan		0:05	1		1			0:10	
	—Deactivate all systems		0:02	1		1			0:04	

REPAIR AEROBRAKE — UNSCHEDULED
SHELTER/MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
	● Repair aerobrake		$\boxed{7:35}$						$\boxed{26:20}$	$\boxed{9:10}$
	Repair shield cloth									
	—Query computer & review maintenace plan	Computer system	1:00	4					4:00	
	—Perform pre-EVA tasks	EVA support equipment	1:00	2		1			4:00	
			||			||				
	—Bring systems on line & activate shelter facilities	Facility controls	1:00		1	1				
	—Translate crew to service area	Cherry picker	0:15			1	2		0:45	0:30
	—Position cherry picker	Cherry picker	0:05			1	2		0:15	0:10
	—Repair & patch damaged shield cloth	Repair materials and tools	0:45			1	2		2:15	1:30

REPAIR AEROBRAKE — UNSCHEDULED
SHELTER/MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
	—Inspect repaired shield cloth	TV system	0:05		1		2		0:15	0:10
	R/R damage radial beam									
	—Reposition cherry picker	Cherry picker	0:05			1	2		0:15	0:10
	—Remove insulation	Insulation release and tie-back tool	0.15			1	2		0:45	0:30
	—Translate EVA crew to safe area	Cherry picker	0:05			1	2		0:15	0:10
	—Activate & position RMS	Shelter RMS	0:05		1	1		2	0:20	0:10
	—Grasp radial beam with RMS	Shelter RMS	0:05		1	1		2	0:20	0:10
	—Translate EVA crew to work area	Cherry picker	0:05			1	2		0:15	0:10
	—Detach radial beam from perimeter cable	Beam extraction tool & cable extension tool	0:10			1	2		0:30	0:20

REPAIR AEROBRAKE — UNSCHEDULED
SHELTER/MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
	—Detach radial beam from radial beam hinge	Latch mechanism	0:10			1	2		0:30	0:20
	—Translate EVA crew to safe area	Cherry picker	0:05			1	2		0:15	0:10
	—Remove radial beam	Shelter RMS	0:05		1	1		2	0:20	0:10
	—Translate radial beam to storage area	Shelter RMS	0:15		1	1		2	1:00	0:30
	—Place in holding fixture & secure	Holding fixture	0:05		1	1		2	0:20	0:10
	—Release RMS	Shelter RMS	0:05		1	1		2	0:20	0:10
	—Grasp replacement radial beam	Shelter RMS	0:05		1	1		2	0:20	0:10
	—Translate radial beam to aerobrake repair area	Shelter RMS	0:15		1	1		2	1:00	0:30
	—Position radial beam for attaching	Shelter RMS	0:05		1	1		2	0:20	0:10

REPAIR AEROBRAKE — UNSCHEDULED
SHELTER/MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
	—Translate EVA crew to work area	Cherry picker	0:05			1	2		0:15	0:10
	—Attach radial beam to radial beam hinge	Latch mechanism	0:15			1	2		0:45	0:30
	—Attach radial beam to perimeter cable	Beam positioning tool & cable stretch tool	0:15			1	2		0:45	0:30
	—Release RMS & stow	Shelter RMS	0:05		1	1		2	0:20	0:10
	—Replace insulation		0:15			1	2		0:45	0:30
	—Inspect radial beam replacement	TV system	0:05		1		2		0:15	0:10
	—Clear & secure work area		0:10		1	1	2		0:40	0:20
	—Translate EVA crew to station	Cherry picker	0:15			1	2		0:45	0:30
	—Perform post-EVA tasks	EVA support equipment	1:00 ||	2		1			3:15	
	—Deactivate facilities	Facility control system	0:15		1	1				

REMOVE & REPLACE TANK MODULE — UNSCHEDULED
SHELTER/MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
	• R/R tank module		$\boxed{16:45}$						$\boxed{58:15}$	$\boxed{20:30}$
	— Day 1 —		(7:35)						(26:10)	(8:40)
	—Query computer & review maintenance plan	Computer system	1:00	4					4:00	
	—Perform pre-EVA tasks	EVA support equipment	1:00 ‖	2		1 ‖			4:00	
	—Bring all systems on line & activate shelter facilities	Facility controls	1:00		1	1				
	—Open tank storage nacelle	Facility controls	0:15 ‖		1	1 ‖			1:00	0:30
	—Transfer EVA crew to maintenance area	Cherry picker	0:15			1	2			
	—Attach crane to tank on OTV	Crane & handling adapter	0:30			1	2		1:30	1:00
	—Release tank/OTV interface	OTV latch mechanism	1:00			1	2		3:00	2:00
	—Translate EVA crew to safe area	Cherry picker	0:05			1	2		0:15	0:10

REMOVE & REPLACE TANK MODULE — UNSCHEDULED
SHELTER/MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
	—Remove tank & transfer to RMS	Shelter RMS & crane	0:30		1	1			2:00	1:00
			||							
	—Translate EVA crew to work area & inspect OTV interface	Cherry picker & TV system	0:20		1	1	2			
	—Translate tank to nacelle storage area	Shelter RMS	0:20		1	1		2	1:20	0:40
	—Position removed tank in storage nacelle holding fixture	RMS & holding fixture	0:20		1	1			1:20	0:40
			||			||				
	—Translate EVA crew to nacelle storage area	Cherry picker	0:20			1	2			
	—Secure tank in holding fixture	Holding fixture latch mechanism	0:30			1	2		1:30	1:00
	—Clear & secure work area		0:30		1		2		1:30	1:00

REMOVE & REPLACE TANK MODULE — UNSCHEDULED
SHELTER/MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
	—Transfer EVA crew to station	Cherry picker	0:20			1	2		1:00	0:40
	—Close nacelle	Facility controls	0:15		1	1			0:30	
	—Perform post-EVA tasks	EVA support equipment	1:00 ||	2		1 ||			3:15	
	—Deactivate all systems	Facility control system	0:15		1	1				
	— Day 2 —		(9:10)						(32:05)	(11:50)
	—Query computer & review maintenance plan	Computer system	1:00	4					4:00	
	—Perform pre-EVA tasks	EVA support equipment	1:00 ||	2		1 ||			4:00	
	—Bring all systems on line & activate shelter facilities	Facility controls	1:00		1	1				
	—Open tank storage nacelle	Facility controls	0:15 ||		1	1 ||			1:00	0:30
	—Translate EVA crew to storage nacelle	Cherry picker	0:15			1	2			

REMOVE & REPLACE TANK MODULE — UNSCHEDULED
SHELTER/MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
	—Grasp replacement tank with RMS	Shelter RMS	0:15		1	1			0:30	
	—Release tank from holding fixture	Holding fixture & latch mechanism	0:20			1	2		1:00	0:40
	—Translate EVA crew to safe area	Cherry picker	0:20			1	2		1:00	0:40
	—Translate tank to crane with RMS	Shelter RMS & crane	0:20		1	1		2	1:20	0:40
	—Close storage nacelle & stow RMS	Facility controls	0:15		1	1		2		
	—Transfer tank to crane & move to OTV	Crane	0:30		1	1		2	2:00	1:00
	—Translate EVA crew to work area	Cherry picker	0:05			1	2		0:15	0:10
	—Inspect OTV/tank interfaces on tank	TV system	0:10		1		2		0:30	0:20

REMOVE & REPLACE TANK MODULE — UNSCHEDULED
SHELTER/MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
	—Translate EVA crew to safe area	Cherry picker	0:05			1	2		0:15	0:10
	—Position tank for mounting	Crane	0:30		1	1		2	2:00	1:00
	—Translate EVA crew to work area	Cherry picker	0:05			1	2		0:15	0:10
	—Attach tank/OTV interface	OTV latch mechanism, facility control	1:00			1	2		3:00	2:00
	—Perform tank/OTV interface inspection & checkout	Station to OTV interface test system	1:00		1	1	2		4:00	2:00
	—Release crane & stow	Crane	0:30		1		2		1:30	1:00
	—Clear & secure work area		0:30		1		2		1:30	1:00
	—Transfer EVA crew to station	Cherry picker	0:15			1	2		0:45	0:30

REMOVE & REPLACE TANK MODULE — UNSCHEDULED
SHELTER/MAINTENANCE MODULE

GROUND TASK	SPACE STATION TASK	SUPPORT EQUIPMENT REQUIREMENTS	FUNCTION DURATION	IVA			EVA		MANHOURS	
				DIRECT	REMOTE	SUPPORT	ACTIVE	STDBY	TOTAL	EVA
	—Perform post-EVA tasks	EVA support equipment	1:00	2		1			3:15	
			||							
	—Deactivate shelter facilities & all other pertinent systems	Facility control system	0:15		1	1				

APPENDIX VI

ISPM NOMINAL FLIGHT OPERATIONS

SEQUENCE OF EVENTS

ORIGINAL PAGE IS
OF POOR QUALITY

INTERNATIONAL SOLAR POLAR MISSION CHRONOLOGY OF EVENTS

FUNCTIONAL REFERENCE ELEMENTS ARE LISTED BY REQUIREMENTS:

THE FIRST ELEMENT LISTED IS THE FUNCTIONAL GROUP THAT IS PRIMARILY AFFECTED BY THE EVENT LISTED IN THE TIMELINE.

SECOND AND ON ELEMENTS ARE THE OTHER FUNCTIONAL GROUPS THAT ARE AFFECTED BY THAT EVENT (SUPPORT GROUPS).

FUNCTIONAL ELEMENTS ARE DEFINED --

A - AVIONICS	O - SAFETY
C - STABILITY & CONTROL	P - MISSION & PERFORMANCE
G - GUIDANCE	PR- PROPULSION
F - FLUIDS	T - THERMAL
M - MECHANICAL	S - STRUCTURAL & STRESS

CREW CONTROL & SUPPORT DEFINITIONS --

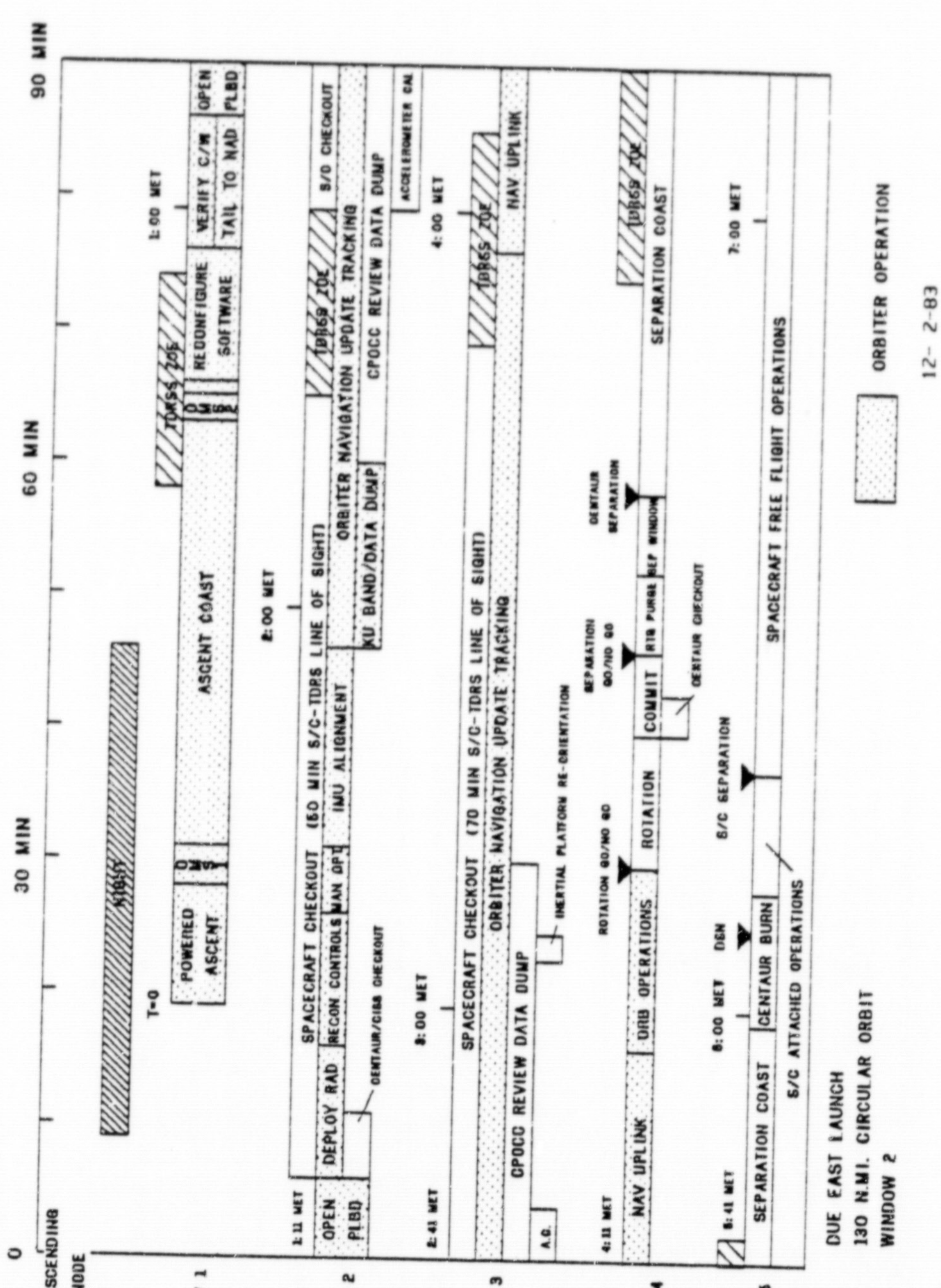
CREW	- CREW INITIATES/CONTROLS EVENT
CMDR	- COMMANDER INITIATES/CONTROLS EVENT
PILOT	- PILOT INITIATES/CONTROLS EVENT
MS	- ACTION OCCURS AT MISSION SPECIALIST STATION
PS	- ACTION OCCURS AT PAYLOAD SPECIALIST STATION
COMP	- ORBITER GENERAL PURPOSE COMPUTER (GPC) CONTROLS EVENT
CRT	- EVENT STATUS MAY BE INPUT/MONITORED/VERIFIED BY CREW VIA CRT READOUT IF DESIRED
SW	- EVENT IS INITIATED BY CREW VIA SWITCH ACTION
CISS	- CENTAUR INTEGRATED SUPPORT SYSTEM CONTROLLED EVENT
SSP	- STANDARD SWITCH PANEL
A6	- NUMBER SIX AFT SWITCH PANEL

OTHER DEFINITIONS --

CCC	- COMMAND, CONTROL, & COMMUNICATIONS
MCC	- MISSION CONTROL CENTER
CPOCC	- CENTAUR PAYLOAD OPERATIONAL CONTROL CENTER
MCCC	- MISSION CONTROL AND COMPUTING CENTER - SPACECRAFT
C&W	- CAUTION & WARNING
TBD	- TO BE DETERMINED
MIL	- MERRITT ISLAND
CU	- CONTROL UNIT -- CISS COMPUTER/CONTROL SYSTEM

ISPM NOMINAL FLIGHT OPERATIONS SEQUENCE OF EVENTS

(REV 4 SEPARATION)



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FLIGHT OPERATIONS FOR CENTAUR-IN-SHUTTLE : ISPM MISSION 12-07-83

EVENT NUMBER	EVENT NAME	OPERATINAL CONTROL SYSTEM	FUNCTIONAL REFERENCE ELEMENT	CREW CONTROL & SUPPORT	START TIME	DURATION	FINISH TIME
6.3	CENTAUR DEPLOYMENT OPERATIONS	ORBITER			1:12:59		
6.3.1.1	INITIATE ISPM UPLOAD-C/O (50 MIN.)	MCCC			1:12:59	0:50:00	2:02:59
6.3.2	CENTAUR/CISS AUTOMATIC CHECKOUT	CISS		CPOCC	1:12:59	0:03:00	1:15:59
6.3.2.1	ANALYZE CENTAUR/CISS DATA AT CPOCC	CPOCC			1:15:59	1:00:00	2:15:59
6.10.3.2	SUNSET				1:20:30	0:31:53	1:52:23
6.2.2.7	RECONFIGURE CONTROLS FOR ON-ORBIT	ORBITER		CREW	1:22:59	0:10:00	1:32:59
6.10.2.8	TDRS E, SIGNAL LOCK-ON	CCC	TDRSS		1:31:00	0:08:00	1:39:00
6.2.2.8	MANUAL OPTICAL SIGHTING	ORBITER		CMDR	1:32:59	0:05:00	1:37:59
6.2.2.9	ORBITER IMU ALIGNMENT	ORBITER		CREW	1:37:59	0:15:00	1:52:59
6.10.2.9	TDRS W, LOS	CCC	TDRSS		1:39:00	0:36:00	2:15:00
6.10.3.3	SUNRISE				1:52:23	0:58:07	2:50:30
6.2.2.10	PURGE FUEL CELLS	ORBITER		CREW	1:52:59	0:15:00	2:07:59
6.2.2.10.1	DEPLOY KU-BAND ANTENNA	ORBITER		CREW	1:52:59	0:02:00	1:54:59
6.2.2.10.2	ACTIVATE KU BAND	ORBITER		CREW	1:54:59	0:00:10	1:55:09
6.2.2.10.3	CCE DOWNLINK BIT RATE TO 64 KBS	ORBITER	A	PILOT	1:55:09	2:45:19	4:40:28
6.2.2.11	ORBITER NAVIGATION UPDATE	MCC			1:55:59	2:30:00	4:25:59
6.2.2.11.1	NAVIGATION UPDATE TRACKING	MCC			1:55:59	2:00:00	3:55:59
6.10.1.3	DUMP PAYLOAD DATA, TRACK 7	ORBITER	A	CRT	2:03:00	0:04:00	2:07:00
6.10.1.4	DUMP P/L DATA IN REWIND, TRACK 8	ORBITER	A	CRT	2:07:00	0:04:00	2:11:00
6.10.1.5	RECORD 64KBS P/L DATA, TRACK 10	ORBITER	A	CRT	2:11:00	1:04:00	3:15:00
6.10.1.20	CPOCC/MCCC REVIEW P/L DATA DUMP	CPOCC			2:11:00	2:29:00	4:40:00
6.10.2.10	TDRS E, LOS	CCC	TDRSS		2:15:00		
6.10.2.11	TDRSS NO COVERAGE AREA	CCC	TDRSS		2:15:00	0:15:00	2:30:00
6.10.2.12	TDRS W, SIGNAL LOCK-ON	CCC	TDRSS		2:30:00	0:36:00	3:06:00
6.2.1.1.1	INHIBIT RCS	ORBITER	C P	CMDR	2:30:00	0:15:00	2:45:00
6.2.1.1.2	ACCELEROMETER BIAS CALIBRATION	CENTAUR	P G D A		2:30:00	0:15:00	2:45:00
6.3.1.2	CONTINUE ISPM UPLOAD-C/O (70 MIN.)	MCCC			2:30:00	1:10:00	3:40:00
6.2.1.1.3	ENABLE RCS	ORBITER	A G D	CMDR	2:45:00		
6.10.3.4	SUNSET				2:50:30	0:31:53	3:22:23
6.1.1.3.11	TERMINATE CISS GHE ENVIRON PURGES	CISS	T F		3:00:00		
6.1.1.3.12	IRU PURGE TURNOFF	CISS	I F A		3:00:00		

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FLIGHT OPERATIONS FOR CENTAUR-IN-SHUTTLE : ISPM MISSION 12-07-83

EVENT NUMBER	EVENT NAME	OPERATNAL CONTROL SYSTEM	FUNCTIONAL REFERENCE ELEMENT	CREW CONTROL & SUPPORT	START TIME	DURATION	FINISH TIME
6.3.4	PERFORM INERTIAL PLATFORM REORIENTATION	CENTAUR	P G D A		3:03:17	0:02:00	3:05:17
6.10.2.13	TDRS E. SIGNAL LOCK-ON	CCC	TDRSS		3:06:00	0:09:00	3:15:00
6.10.2.14	TDRS W. LOS	CCC	TDRSS		3:15:00	0:35:00	3:50:00
6.10.1.6	RECORD 64KBS P/L DATA, TRACK 11	ORBITER	A	CRT	3:15:00	1:04:00	4:19:00
6.10.3.5	SUNRISE				3:22:23	0:58:07	4:20:30
6.10.2.15	TDRS E. LOS	CCC	TDRSS		3:50:00		
6.10.2.16	TDRSS NO COVERAGE AREA	CCC	TDRSS		3:50:00	0:16:00	4:06:00
6.2.2.11.2	NAV UPDATE COMPUTATION & UPLINK	MCC			3:55:59	0:30:00	4:25:59
6.10.2.17	TDRS W. SIGNAL LOCK-ON	CCC	TDRSS		4:06:00	0:35:00	4:41:00
6.10.1.7	DUMP PAYLOAD DATA, TRACK 10	ORBITER	A	CRT	4:19:00	0:04:00	4:23:00
6.10.3.6	SUNSET				4:20:30	0:31:53	4:52:23
6.10.1.8	DUMP PAYLOAD DATA IN REWIND, TRACK 9	ORBITER	A	CRT	4:23:00	0:04:00	4:27:00
6.10.1.9	RECORD 64KBS P/L DATA, TRACK 12	ORBITER	A	CRT	4:27:00	1:04:00	5:31:00
6.3.4.7	REORIENT TO CENTAUR DEPLOYMENT ATT	ORBITER	G A	CMDR	4:32:00	0:08:00	4:40:00
6.3.4.8	SETUP PHOTO/VIDEOTAPE FOR SEPARATION	ORBITER		PILOT	4:32:00	0:08:00	4:40:00
6.3.4.9	RECEIVE ROTATION GO/NOGO FROM MCCC/CPOCC	MCCC/CPOCC		CREW	4:40:00		
6.3.5	CENTAUR/S/C ROTATION SEQUENCE	CISS			4:40:28	0:09:56	4:50:24
6.3.5.1	PRE-LATCH RELEASE SEQUENCE	ORBITER		CMDR	4:40:28	0:00:25	4:40:53
6.3.5.1.1	DEACTIVATE KU BAND	ORBITER		CMDR	4:40:28	0:00:10	4:40:38
6.10.1.32	CCE DOWNLINK BIT RATE TO 32 KBPS	ORBITER	A	PILOT	4:40:28	0:13:31	4:53:59
6.3.5.1.2	INHIBIT ORBITER PRIMARY RCS	ORBITER		CMDR	4:40:28	0:09:56	4:50:24
6.3.5.1.3	ACTIVATE AC SOURCES 1 AND 2	ORBITER		A6 SW	4:40:33	0:00:15	4:40:48
6.3.5.1.4	ENGAGE PRIMARY DRIVE UNIT CLUTCH	CISS		SSP SW	4:40:53	0:00:30	4:41:23
6.10.2.18	TDRS E. SIGNAL LOCK-ON	CCC	TDRSS		4:41:00	0:10:00	4:51:00
6.3.5.1.5	VERIFY SUCCESSFUL CLUTCH ENGAGEMENT	ORBITER		SSP IND	4:41:23		
6.3.5.2	LATCH RELEASE SEQUENCE	ORBITER	M		4:41:23	0:01:00	4:42:23
6.3.5.2.1	RELEASE LONGERON TRUNNION LATCHES	ORBITER	M	A6 SW	4:41:23	0:00:30	4:41:53
6.3.5.2.2	VERIFY UNLATCHED TRUNNION LATCHES	ORBITER	M A	INDICATOR	4:41:53		
6.3.5.2.3	RELEASE KEEL LATCH	ORBITER	M	A6 SW	4:41:53	0:00:30	4:42:23
6.3.5.2.4	VERIFY UNLATCHED KEEL LATCH	ORBITER	M A	INDICATOR	4:42:23	0:00:01	4:42:24
6.3.5.3	ROTATION SEQUENCE	CISS	M A		4:42:24	0:08:00	4:50:24
6.3.5.3.1	ACTIVATE DEPLOYMENT ADAPTER ROTATION	CISS	M	SSP SW	4:42:24		
6.3.5.3.4	MONITER CRANK ANGLE	ORBITER			4:42:24	0:08:00	4:50:24
6.3.5.3.2	VERIFY ROTATION COMPLETE	CISS	M A	CRT	4:50:24		
6.3.5.3.3	ENABLE ORBITER PRIMARY RCS	ORBITER		CMDR	4:50:24	0:00:05	4:50:29
6.3.7.2	CENTAUR AUTOMATIC CHECKOUT	CISS	A	CPOCC	4:50:29	0:03:00	4:53:29
6.10.2.19	TDRS W. LOS	CCC	TDRSS		4:51:00	0:34:00	5:25:00
6.10.3.7	SUNRISE				4:52:23	0:58:07	5:50:30
6.3.7	INITIATE CENTAUR & S/C COMMIT SEQUENCE	CISS	A	SSP SW	4:53:29	0:02:35	4:56:04
6.3.7.1	TRANSFER TO CENTAUR INTERNAL POWER	CENTAUR	A	CRT	4:53:29	0:00:30	4:53:59
6.3.7.1.1	VERIFY ELECTRICAL SYSTEM	CPOCC	A	CRT	4:53:29	0:00:30	4:53:59
6.10.1.33	SWITCH TO 16KBS FLIGHT FORMAT	ORBITER	A	CRT	4:53:59	1:02:31	5:56:30
6.3.7.1.3	ENERGIZE RF SYSTEM	CENTAUR	A	CRT	4:53:59	0:00:01	4:54:00
6.3.7.1.4	VERIFY RF LINK	ORBITER		CRT	4:54:00	0:05:00	4:59:00
6.3.7.3	CONFIGURE FLUID SYSTEMS FOR SEPARATION	CISS	F A		4:54:49	0:01:15	4:56:04
6.3.7.3.1	ADJUST VENT LEVELS	CISS	F A		4:54:49	0:00:05	4:54:54
6.3.7.3.2	VERIFY CENTAUR VENT VALVES CLOSED	CISS	F A	CRT	4:54:54		

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FLIGHT OPERATIONS FOR CENTAUR-IN-SHUTTLE : ISPM MISSION 12-07-83

EVENT NUMBER	EVENT NAME	OPERATNAL CONTROL SYSTEM	FUNCTIONAL REFERENCE ELEMENT	CREW CONTROL & SUPPORT	START TIME	DURATION	FINISH TIME
6.3.7.3.3	VERIFY CENTAUR DUMP VALVES CLOSED	CISS	F A	CRT	4:54:54		
6.3.7.3.4	CYCLE CISS DUMP VALVES	CISS	F A		4:54:54	0:00:09	4:55:03
6.3.7.3.5	CLOSE CISS INFLIGHT VENT VALVES	CISS	F A		4:54:59	0:00:04	4:55:03
6.3.7.3.6	VERIFY CISS VENT VALVES CLOSED	CISS	F A	CRT	4:55:03	0:00:01	4:55:04
6.3.7.3.7	VERIFY CISS DUMP VALVES CLOSED	CISS	F A	CRT	4:55:03	0:00:01	4:55:04
6.3.7.3.8	MONITOR LINES FOR PRESSURE BUILDUP	CISS	F A	CRT	4:55:03	0:05:00	5:00:03
6.3.7.3.9	VENT & TANK PRESS'N CONTROL INHIBITED	CISS	F A		4:55:03	0:18:17	5:13:20
6.3.7.3.10	PROPELLANT DUMP VALVES INHIBITED	CISS	F A	CRT	4:55:03		
6.3.7.3.11	VERIFY STATUS OF VENT & DUMP VALVES	CPOCC	A	CRT	4:55:04	0:01:00	4:56:04
6.3.7.3.13	VERIFY COMMIT SEQUENCE SUCCESSFUL	ORBITER		SSP IND	4:55:04	0:01:00	4:56:04
6.3.7.2.1	RECEIVE SEPARATION GO/NO GO FROM GND	MCCC/CPOCC		CREW	4:56:04		
6.3.7.4	S/C RTG COOLING PURGE SEQUENCE	ORBITER	F A		4:56:05	0:06:00	5:02:05
6.3.7.4.1	TURN OFF S/C RTG COOLANT PUMP	ORBITER		CMDR	4:56:05		
6.3.7.4.2	PURGE S/C RTG COOLANT LOOP	ORBITER		CMDR	4:56:05	0:06:00	5:02:05
6.5.1.1	PHOTO/VIDEOTAPE COVERAGE	ORBITER		CREW	4:57:05	0:21:00	5:18:05
6.3.7.4.3	HOLD -- SEPARATION WINDOW				5:02:05	0:06:00	5:08:05
6.3.8	CENTAUR SEPARATION SEQUENCE	ORBITER			5:08:05		
6.3.8.1	SEPARATION SEQUENCE	ORBITER	A	SSP SW	5:08:10	0:00:10	5:08:20
6.3.7.3.12	INHIBIT ORBITER PRIMARY & VERNIER RCS	ORBITER		CMDR	5:08:15	0:01:05	5:09:20
6.3.8.2	ARM SUPER*ZIP SEPARATION DEVICE	CISS	A		5:08:20		
6.3.8.3	FIRE SUPER*ZIP	CISS	A		5:08:20		
6.3.8.4	VERIFY SEPARATION	CISS	A M	CREW	5:08:20		
6.4	CENTAUR FREE-FLIGHT OPERATIONS	CENTAUR			5:08:20	1:17:04	6:25:24
6.4.1	SEPARATION COAST SEQUENCE	CENTAUR			5:08:20	0:05:00	5:13:20
6.4.1.1	START CENTAUR TIMERS - SEPARATION	CENTAUR	M A		5:08:20		
6.5	ORBITER POST-DEPLOY CENTAUR/CISS SUPPORT	ORBITER			5:08:20	1:08:04	6:16:24
6.5.1	OBSERVE CENTAUR - FREE FLIGHT	ORBITER		CREW	5:08:20	1:00:00	6:08:20
6.5.4	SUPPORT CCC FOR CENTAUR	ORBITER			5:08:20	0:13:00	5:21:20
6.4.1.2	DEPLOY CENTAUR ANTENNAS	CENTAUR	A		5:08:35	0:00:01	5:08:36
6.5.2.1	ENABLE ORBITER PRIMARY & VERNIER RCS	ORBITER		CMDR	5:09:20	0:00:05	5:09:25
6.5.3	CISS SAFING SEQUENCE	ORBITER			5:09:20	0:00:10	5:09:30
6.5.3.1	ROTATE CISS DOWN.	CISS			5:09:20	0:05:00	5:14:20
6.5.3.2	VENT/PURGE CISS HELIUM SUPPLY	CISS	F A		5:09:20	2:00:00	7:09:20
6.5.2.2	POINT ORBITER PI ANTENNA AT CENTAUR	ORBITER		CMDR	5:09:25	0:48:00	5:57:25
6.4.2	CENTAUR PRE-MES COAST SEQUENCE	CENTAUR			5:13:20		
6.4.2.0.1	TIMERS TIME OUT (5 MIN.)	CENTAUR	A		5:13-20		
6.4.2.1.1	HARDWARE TIMERS INITIATE SIGNAL	CENTAUR	A		5:13:20		
6.4.2.1.2	DCU SEQUENCER INITIATES SIGNAL	CENTAUR	A D		5:13:20		
6.4.2.2	ARM CENTAUR RCS & TANK PRESS'N CNTRL	CENTAUR	A F D		5:13:20		
6.4.2.2.1	OPEN N2H4 PYRO ISOLATION VALVES	CENTAUR	F A D		5:13:20		
6.4.2.2.2	OPEN N2H4 PYRO PRESSURE VALVES	CENTAUR	F A D		5:13:20	0:00:10	5:13:30
6.4.2.2.3	ENABLE VENT & TANK PRESS'N CONTROL	CENTAUR	F A D		5:13:20		
6.4.2.2.4	OPEN VENT FYRO ISOLATION VALVES	CENTAUR	F A D		5:13:20		
6.4.2.4.1	FIRE RTG PRESSURE RELEASE DEVICE	CENTAUR			5:13:20		

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EVENT NUMBER	EVENT NAME	OPERATNAL CONTROL SYSTEM	FUNCTIONAL REFERENCE ELEMENT	CREW CONTROL & SUPPORT	START TIME	DURATION	FINISH TIME
6.5.2	ORBITER SAFETY MANEUVERS	ORBITER		CMDR	5:13:20	0:15:00	5:28:20
6.4.2.3	ACTIVATE P/Y MOTORS	CENTAUR	G A D		5:13:30		
6.4.2.5	COAST ORIENTATION	CENTAUR	G		5:13:40		
6.4.2.5.1	THRUSTER WARMING FIRING	CENTAUR	C D		5:13:40	0:00:10	5:13:50
6.4.2.3.1	BEGIN SLOW ROLL (.1 RPM)	CENTAUR	P G D		5:14:00	0:39:00	5:53:00
6.4.2.5.2	MAINTAIN CENTAUR TAIL TO SUN ATTITUDE	CENTAUR	P G T D		5:14:00	0:39:20	5:53:20
6.5.4.2	DEACTIVATE AC SOURCES 1 AND 2	ORBITER		A6 SW	5:14:20		
6.5.4.1	ACTIVATE KU-BAND	ORBITER		CREW	5:21:20	0:05:00	5:26:20
6.10.2.20	TDRS E, LOS	CCC	TDRSS		5:25:00		
6.10.2.21	TDRSS NO COVERAGE AREA	CCC	TDRSS		5:25:00	0:18:00	5:43:00
6.10.1.10	RECORD 64KBS P/L DATA, TRACK 13	ORBITER	A	CRT	5:31:00	1:04:00	6:35:00
6.10.2.22	TDRS W, SIGNAL LOCK-ON	CCC	TDRSS		5:43:00		
6.4.2.6	DEACTIVATE-CENTAUR-TO-ORBITER RF LINK	CENTAUR	A D		5:43:00		
6.4.2.6.1	ACTIVATE RF LINK TO TDRSS W	CENTAUR	A D		5:43:10	0:02:00	5:45:10
6.10.3.8	SUNSET				5:50:30	0:31:53	6:22:23
6.4.2.9	START CENTAUR PROP SETTLING: 2S ON	CENTAUR	T G A F D		5:51:55	0:05:45	5:57:40
6.4.2.3.2	DESPIN CENTAUR	CENTAUR	P G D		5:53:00	0:00:30	5:53:30
6.4.2.1	TIMERS TIME OUT (45 MIN.)	CENTAUR	A		5:53:20		
6.4.2.8	REORIENT CENTAUR TO BURN ATTITUDE	CENTAUR	P G A D		5:53:20	0:03:00	5:56:20
6.4.2.6.2	SWITCH TO 32 KBS FORMAT	CENTAUR	A		5:56:30	0:12:04	6:08:34
6.4.3	ACTIVATE PRE-MES SEQUENCE	CENTAUR	F A D		5:57:20	0:01:00	5:58:20
6.4.3.1	ARM CENTAUR MAIN ENGINE- OPEN PREVALVE	CENTAUR	A F D		5:57:20		
6.4.3.2	HYDRAULIC RECIRCULATION MOTORS - ON	CENTAUR	F A D		5:57:20	0:01:12	5:58:32
6.4.3.3	OPEN PRESTART VALVES	CENTAUR	F A D		5:57:30	0:00:10	5:57:40
6.4.2.10	INCREASE CENT PROP SETTLING: 4S ON	CENTAUR	T G A F D		5:57:40	0:00:45	5:58:25
6.4.3.4	CLOSE PRESTART VALVES	CENTAUR	F A D		5:57:40		
6.4.3.5	INHIBIT ZERO-G VENT SYSTEM	CENTAUR	F A D		5:57:45		
6.4.3.6	START LO2 AND LH2 TANK PRESSURIZATION	CENTAUR	F A D		5:57:45	0:00:35	5:58:20
6.4.3.7	OPEN PRESTART VALVES	CENTAUR	F A D		5:58:11	0:10:13	6:08:24
6.4.4	CENTAUR BURN SEQUENCE	CENTAUR			5:58:20	0:10:04	6:08:24
6.4.4.1	OPEN START VALVES	CENTAUR	F A D		5:58:20	0:10:04	6:08:24
6.4.4.2	IGNITERS ON - MAIN ENGINE START	CENTAUR	F A D		5:58:20	0:00:04	5:58:24